COMM ACADEMY 2013

DESIGN AND ENGINEERING OF A PUBLIC SAFETY GRADE RADIO SITE

Andy Ruschak KK7TR

Agenda

- Radio Shelter Types and Designs
- Tower Design and Considerations
- Standby/emergency power systems
- Site RF grounding – Motorola R56
- Microwave Backhaul Components and Design

Background

- Many design considerations go into modern PS Radio site engineering and construction
- Good engineering practice is identical to amateur radio except implemented to a higher "construct-able" level

Background

- Many hams never get the opportunity to see inside PS radio site installations
- Mission-critical and life-safety reliability are the ultimate goals of a quality design

Site Equipment Shelters

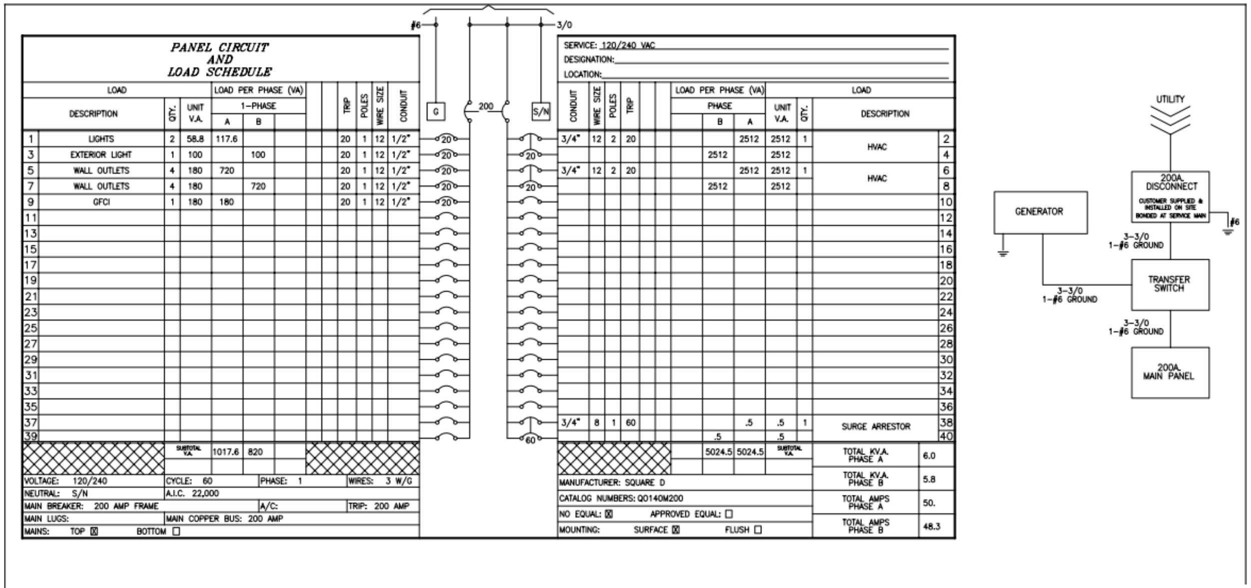
- Most visible element (next to tower)
- Protection Level vs. Cost

Site Equipment Shelters

- Fiberglass, Composite, CMU block, CONEX
  Lightweight (wood or steel stud) and Precast Concrete styles
- Slab or perimeter foundations – affect floor strength (loading)
- Purchaser can now specify ballistic levels of armor protection
- Sites considered National Critical Infrastructure are hardened

Equipment Shelters

- Built-to-design at factory, local code requirements apply
- Typically interior wiring, grounding, cable trays, transfer switch, panel entry ports, fire suppression and HVAC installed at factory



PANEL CIRCUIT AND LOAD SCHEDULE

	LOAD			LOAD PER PHASE (VA)								
	DESCRIPTION	QTY.	UNIT V.A.	1-PHASE A	1-PHASE B				TRIP	POLES	WIRE SIZE	CONDUIT
1	LIGHTS	2	58.8	117.6					20	1	12	1/2"
3	EXTERIOR LIGHT	1	100		100				20	1	12	1/2"
5	WALL OUTLETS	4	180	720					20	1	12	1/2"
7	WALL OUTLETS	4	180		720				20	1	12	1/2"
9	GFCI	1	180	180					20	1	12	1/2"
11												
13												
15												
17												
19												
21												
23												
25												
27												
29												
31												
33												
35												
37												
39												
		SUBTOTAL V.A.		1017.6	820							

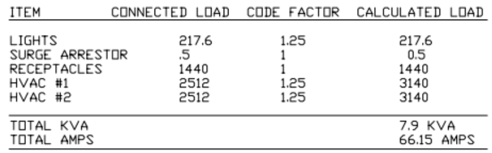
VOLTAGE: 120/240	CYCLE: 60	PHASE: 1	WIRES: 3 W/G
NEUTRAL: S/N	A.I.C. 22,000		
MAIN BREAKER: 200 AMP FRAME		A/C:	TRIP: 200 AMP
MAIN LUGS:	MAIN COPPER BUS: 200 AMP		
MAINS: TOP ☒ BOTTOM ☐			

SERVICE: 120/240 VAC
DESIGNATION:
LOCATION:

						LOAD PER PHASE (VA)			LOAD			
CONDUIT	WIRE SIZE	POLES	TRIP				PHASE B	PHASE A	UNIT V.A.	QTY.	DESCRIPTION	
3/4"	12	2	20					2512	2512	1	HVAC	2
							2512		2512			4
3/4"	12	2	20					2512	2512	1	HVAC	6
							2512		2512			8
												10
												12
												14
												16
												18
												20
												22
												24
												26
												28
												30
												32
												34
												36
3/4"	8	1	60					.5	.5	1	SURGE ARRESTOR	38
							.5		.5			40
							5024.5	5024.5	SUBTOTAL V.A.			

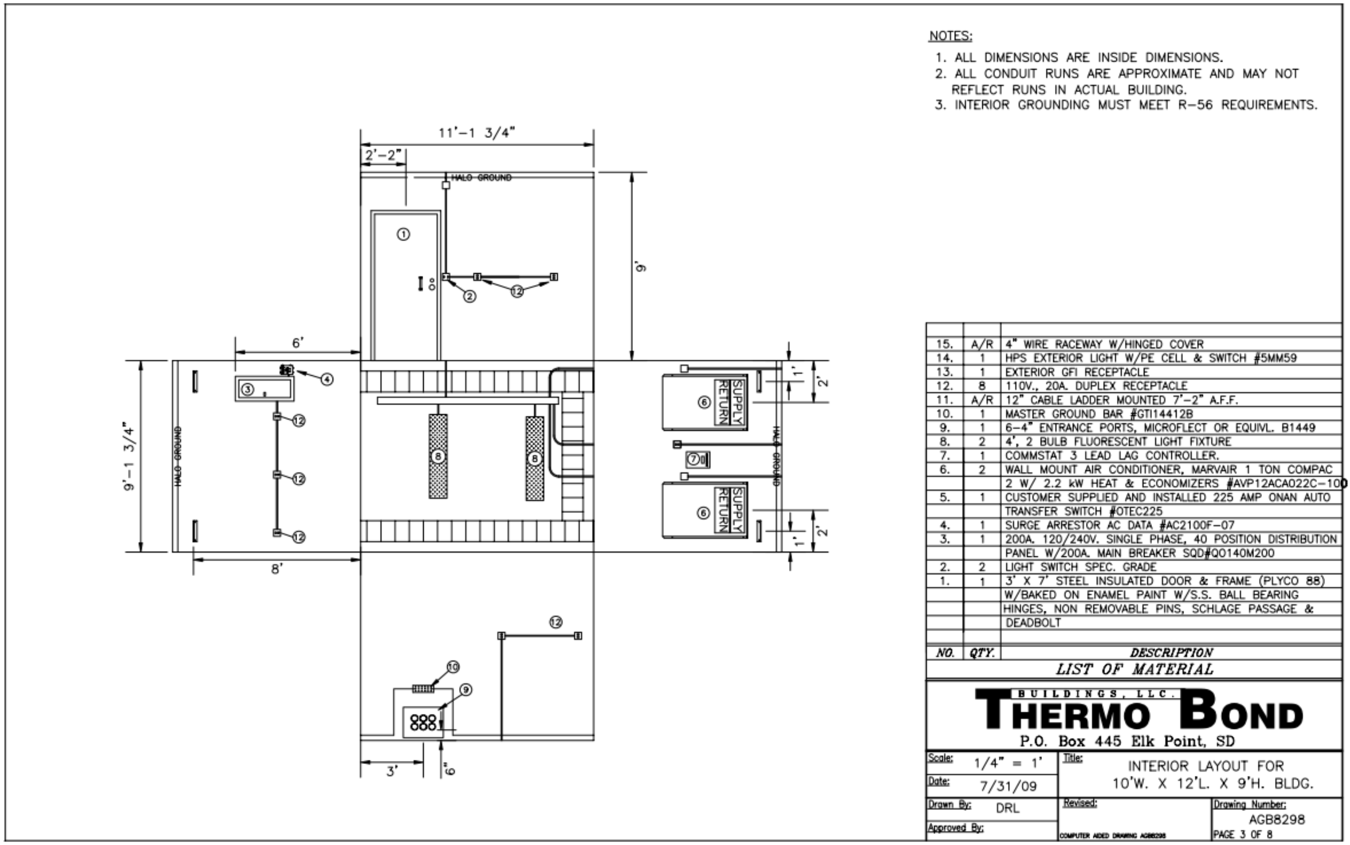
MANUFACTURER: SQUARE D	TOTAL KV.A. PHASE A: 6.0
CATALOG NUMBERS: Q0140M200	TOTAL KV.A. PHASE B: 5.8
NO EQUAL: ☒ APPROVED EQUAL: ☐	TOTAL AMPS PHASE A: 50.
MOUNTING: SURFACE ☒ FLUSH ☐	TOTAL AMPS PHASE B: 48.3

- Appropriate sizing of load center important
- ATS and disconnect must be specified correctly



ITEM	CONNECTED LOAD	CODE FACTOR	CALCULATED LOAD
LIGHTS	217.6	1.25	217.6
SURGE ARRESTOR	.5	1	0.5
RECEPTACLES	1440	1	1440
HVAC #1	2512	1.25	3140
HVAC #2	2512	1.25	3140
TOTAL KVA			7.9 KVA
TOTAL AMPS			66.15 AMPS

- Overhead cable trays, drops and lighting equally important
- Rack and equipment setback should adhere to code



NOTES:
1. ALL DIMENSIONS ARE INSIDE DIMENSIONS.
2. ALL CONDUIT RUNS ARE APPROXIMATE AND MAY NOT REFLECT RUNS IN ACTUAL BUILDING.
3. INTERIOR GROUNDING MUST MEET R-56 REQUIREMENTS.

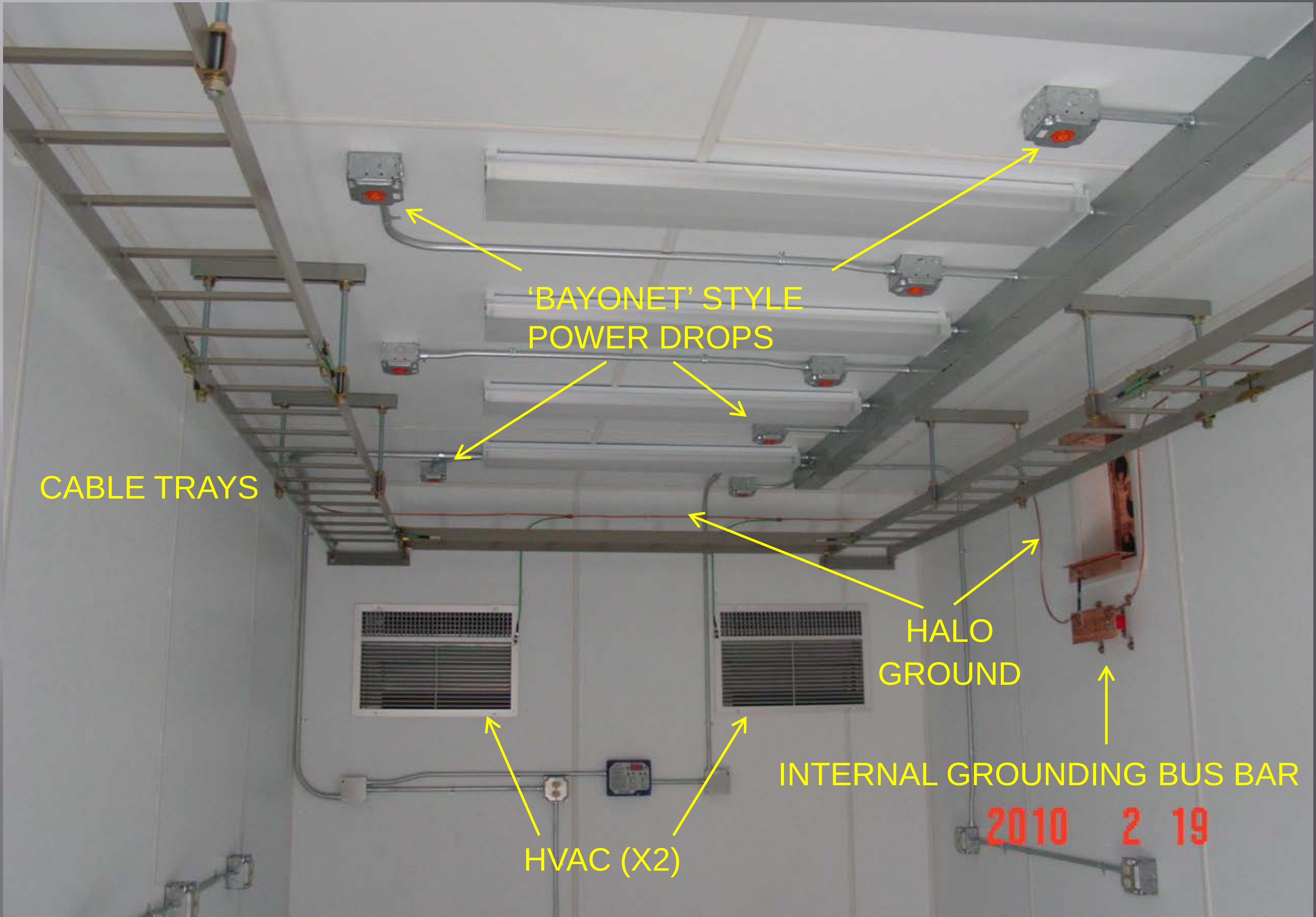
NO.	QTY.	DESCRIPTION
15.	A/R	4" WIRE RACEWAY W/HINGED COVER
14.	1	HPS EXTERIOR LIGHT W/PE CELL & SWITCH #5MM59
13.	1	EXTERIOR GFI RECEPTACLE
12.	8	110V., 20A. DUPLEX RECEPTACLE
11.	A/R	12" CABLE LADDER MOUNTED 7'-2" A.F.F.
10.	1	MASTER GROUND BAR #GTI14412B
9.	1	6-4" ENTRANCE PORTS, MICROFLECT OR EQUIVL. B1449
8.	2	4', 2 BULB FLUORESCENT LIGHT FIXTURE
7.	1	COMMSTAT 3 LEAD LAG CONTROLLER.
6.	2	WALL MOUNT AIR CONDITIONER, MARVAIR 1 TON COMPAC 2 W/ 2.2 kW HEAT & ECONOMIZERS #AVP12ACA022C-100
5.	1	CUSTOMER SUPPLIED AND INSTALLED 225 AMP ONAN AUTO TRANSFER SWITCH #OTEC225
4.	1	SURGE ARRESTOR AC DATA #AC2100F-07
3.	1	200A. 120/240V. SINGLE PHASE, 40 POSITION DISTRIBUTION PANEL W/200A. MAIN BREAKER SQD#Q0140M200
2.	2	LIGHT SWITCH SPEC. GRADE
1.	1	3' X 7' STEEL INSULATED DOOR & FRAME (PLYCO 88) W/BAKED ON ENAMEL PAINT W/S.S. BALL BEARING HINGES, NON REMOVABLE PINS, SCHLAGE PASSAGE & DEADBOLT

LIST OF MATERIAL

THERMO BOND BUILDINGS, LLC.
P.O. Box 445 Elk Point, SD

Scale: 1/4" = 1'
Date: 7/31/09
Title: INTERIOR LAYOUT FOR 10'W. X 12'L. X 9'H. BLDG.
Drawn By: DRL
Approved By:
Revised:
COMPUTER AIDED DRAWING AGB8298
Drawing Number: AGB8298
PAGE 3 OF 8

Equipment Shelters



Equipment Shelters

Shelter installation is a logistical challenge

- Size, weight, season/weather dictate related transport requirements
- State legal requirements (L&I) and stamps/permits
- Remote sites inaccessible during winter months
- Crane access at site, how large?

Equipment Shelters

Why such detail is shelter planning?

- You get one chance to do it right
- Protected equipment expensive ($100's of thousands to millions per site)
- Protected lives invaluable

Towers

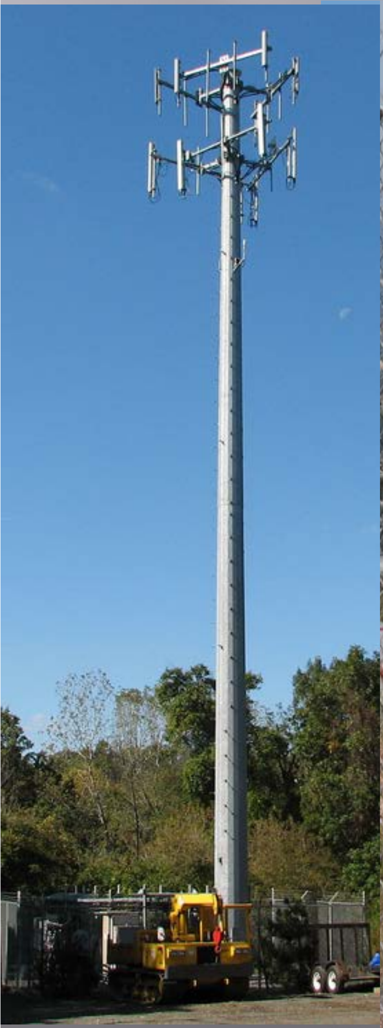
The foundation (literally) of a communications system

- Location, design and height factors into a myriad of wireless considerations
  ex. coverage, licensing, antenna style, permitting
- Significant investment that must survive multiple considerations such as time, appurtenance loading, mother nature
- Typical designs include
  Guyed
  Self-supporting (Lattice, Monopole)
  Rooftop or water tank mount
  "Hot" (AM Broadcast)
  Other (telephone pole, wood laminate

Towers

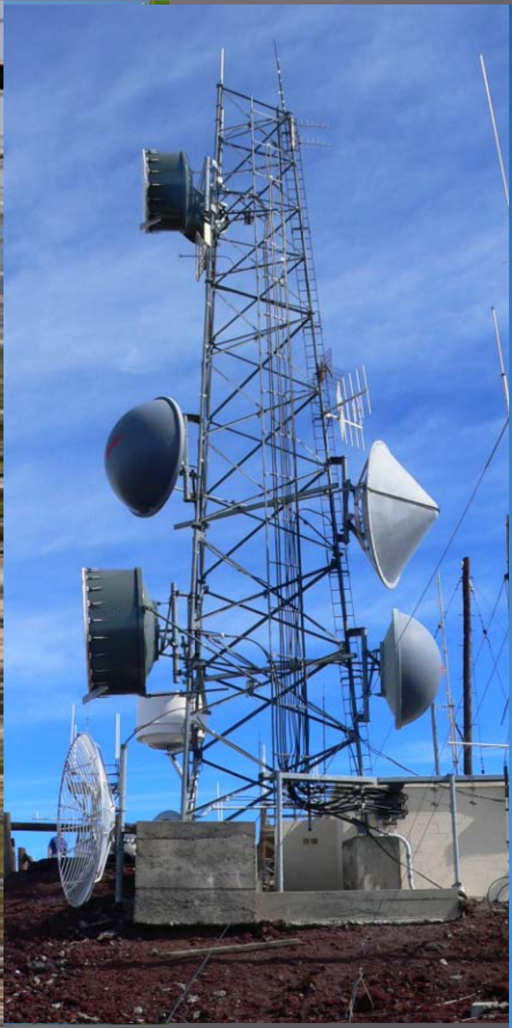
Examples of common tower types

Monopole

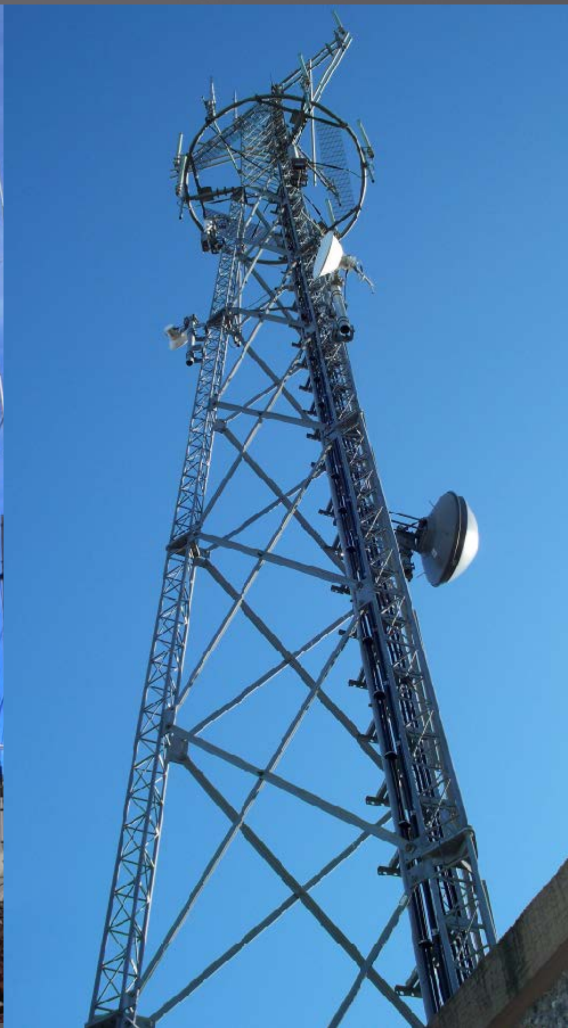


Guyed

Lattice



Pirod



Towers

Most towers are unique and custom built for the customer

Many design considerations of which cost is just one component"

- Optimal style
- Base pad and real estate/area
- Not just strength but stiffness
- Gauge of steel
- Cross member bracing

Common Manufacturers include:

- Valmont Microflect™ and PiRod™
- Rohn SSV series (hams know G series)

Towers

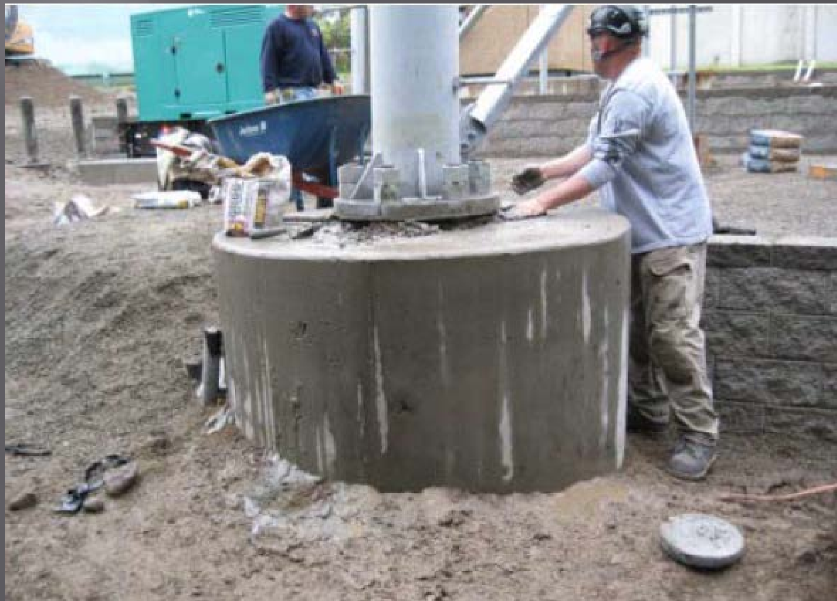
So you want to build a tower? not so fast…

- First obstacle is permitting for construction
- NIER Study/Report (Non-Ionizing Exposure to Radiation)
- Geotechnical study
- SEPA (State Environmental Policy Act)
- Archeological study (Native/Tribal burial site review)
- May require public review process

Towers

Soil samples and core drilling critical…

- What is composition of soil?
- Bedrock, clay, glacial till, sand, volcanic
- Also ties into grounding
- Concrete “recipe” critical (porosity, temperature, etc.)
- Slab dimensions and Pier depth critical
- Often need to add counterbalance weight with concrete over-pour



Towers

- Geotechnical study
- ANSI EIA/TIA-222G standard (replaces F) is the Structural Standard for Antenna Supporting Structures and Antennas
- Many stresses on a tower

  - Weight

  - Rotational Torque*

  - Sway*

  -Temperature

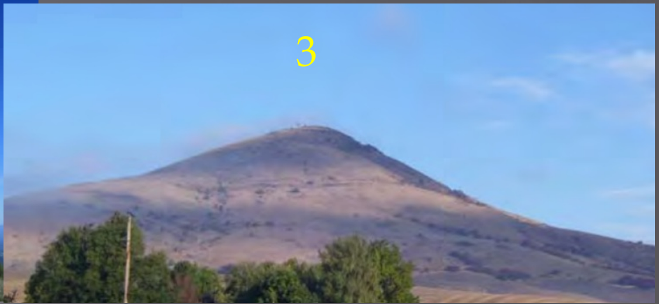
* critical for MW links

Towers

Many related to Geographical location and topography

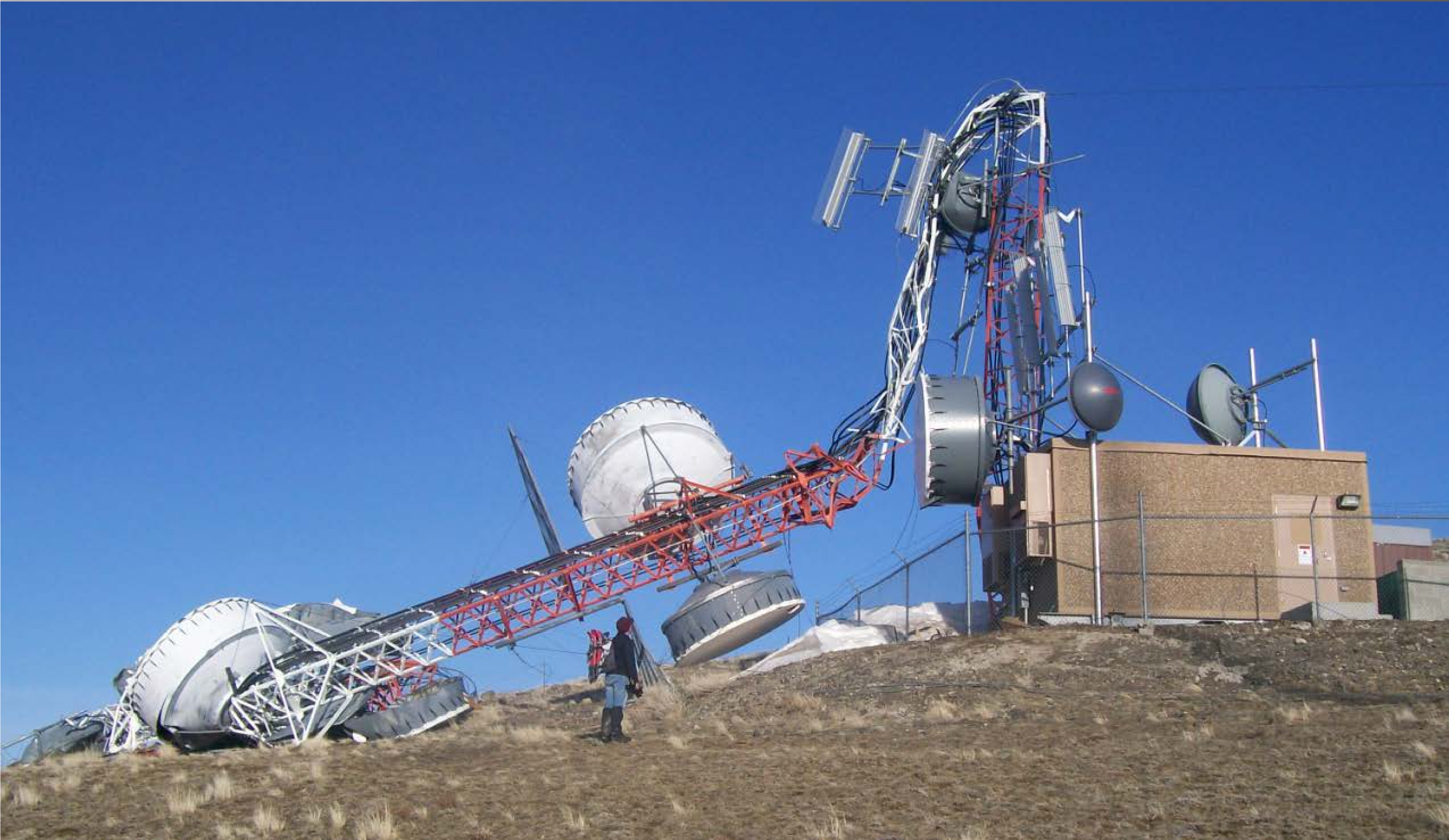
- Exposure Categories:
  (B) Forest, (C) Open Terrain, (D) Shorelines
- Topographical Categories:
  (1) No abrupt changes, (2) Crest of escarpment
  (3) Upper half of hill, (4) Upper half of ridge

- Different analysis based upon tower type



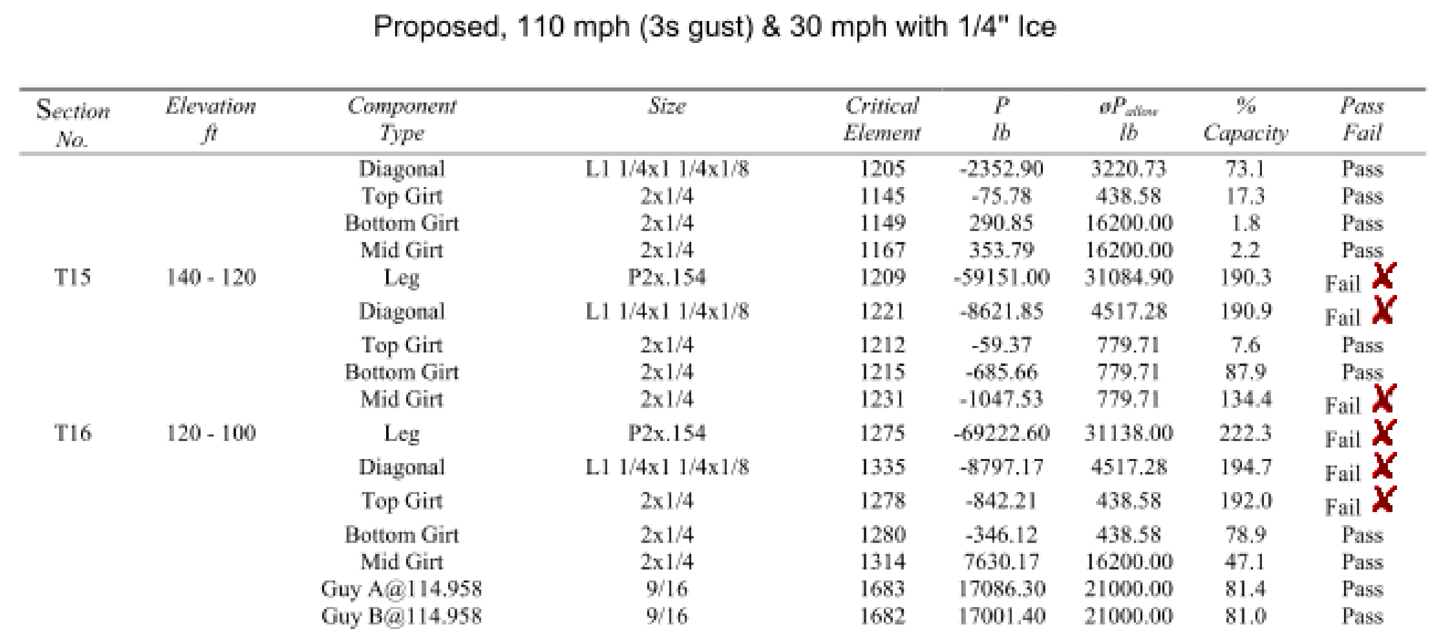
Towers

You gotta get it right the first time….



Towers

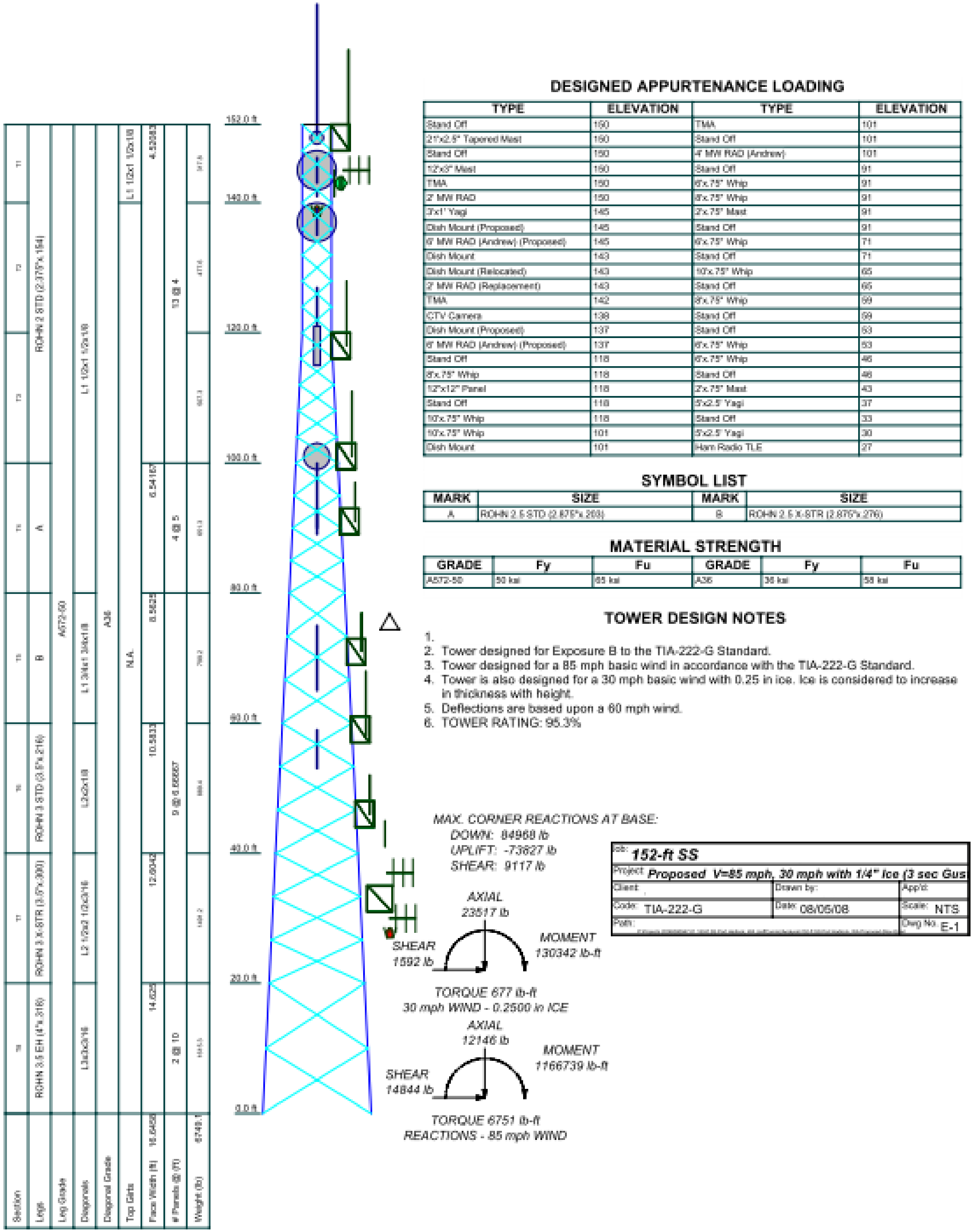
- Existing towers must get structural analysis reports updated when adding appurtenances
- Sometimes towers can be strengthened in-place
  - grouting legs
  - steel cross members



Proposed, 110 mph (3s gust) & 30 mph with 1/4" Ice

Section No.	*Elevation ft*	*Component Type*	*Size*	*Critical Element*	*P lb*	*ϕP_{allow} lb*	*% Capacity*	*Pass Fail*
		Diagonal	L1 1/4x1 1/4x1/8	1205	-2352.90	3220.73	73.1	Pass
		Top Girt	2x1/4	1145	-75.78	438.58	17.3	Pass
		Bottom Girt	2x1/4	1149	290.85	16200.00	1.8	Pass
		Mid Girt	2x1/4	1167	353.79	16200.00	2.2	Pass
T15	140 - 120	Leg	P2x.154	1209	-59151.00	31084.90	190.3	Fail ✗
		Diagonal	L1 1/4x1 1/4x1/8	1221	-8621.85	4517.28	190.9	Fail ✗
		Top Girt	2x1/4	1212	-59.37	779.71	7.6	Pass
		Bottom Girt	2x1/4	1215	-685.66	779.71	87.9	Pass
		Mid Girt	2x1/4	1231	-1047.53	779.71	134.4	Fail ✗
T16	120 - 100	Leg	P2x.154	1275	-69222.60	31138.00	222.3	Fail ✗
		Diagonal	L1 1/4x1 1/4x1/8	1335	-8797.17	4517.28	194.7	Fail ✗
		Top Girt	2x1/4	1278	-842.21	438.58	192.0	Fail ✗
		Bottom Girt	2x1/4	1280	-346.12	438.58	78.9	Pass
		Mid Girt	2x1/4	1314	7630.17	16200.00	47.1	Pass
		Guy A@114.958	9/16	1683	17086.30	21000.00	81.4	Pass
		Guy B@114.958	9/16	1682	17001.40	21000.00	81.0	Pass

Tower Design and Analysis is a Specialized Discipline



DESIGNED APPURTENANCE LOADING

TYPE	ELEVATION	TYPE	ELEVATION
Stand Off	150	TMA	101
21'x2.5" Tapered Mast	150	Stand Off	101
Stand Off	150	4' MW RAD (Andrew)	101
12'x3" Mast	150	Stand Off	91
TMA	150	6'x.75" Whip	91
2' MW RAD	150	8'x.75" Whip	91
3'x1' Yagi	145	2'x.75" Mast	91
Dish Mount (Proposed)	145	Stand Off	91
6' MW RAD (Andrew) (Proposed)	145	6'x.75" Whip	71
Dish Mount	143	Stand Off	71
Dish Mount (Relocated)	143	10'x.75" Whip	65
2' MW RAD (Replacement)	143	Stand Off	65
TMA	142	8'x.75" Whip	59
CTV Camera	138	Stand Off	59
Dish Mount (Proposed)	137	Stand Off	53
6' MW RAD (Andrew) (Proposed)	137	6'x.75" Whip	53
Stand Off	118	6'x.75" Whip	46
8'x.75" Whip	118	Stand Off	46
12"x12" Panel	118	2'x.75" Mast	43
Stand Off	118	5'x2.5' Yagi	37
10'x.75" Whip	118	Stand Off	33
10'x.75" Whip	101	5'x2.5' Yagi	30
Dish Mount	101	Ham Radio TLE	27

SYMBOL LIST

MARK	SIZE	MARK	SIZE
A	ROHN 2.5 STD (2.875"x.203)	B	ROHN 2.5 X-STR (2.875"x.276)

MATERIAL STRENGTH

GRADE	Fy	Fu	GRADE	Fy	Fu
A572-50	50 ksi	65 ksi	A36	36 ksi	58 ksi

TOWER DESIGN NOTES

1.
2. Tower designed for Exposure B to the TIA-222-G Standard.
3. Tower designed for a 85 mph basic wind in accordance with the TIA-222-G Standard.
4. Tower is also designed for a 30 mph basic wind with 0.25 in ice. Ice is considered to increase in thickness with height.
5. Deflections are based upon a 60 mph wind.
6. TOWER RATING: 95.3%

MAX. CORNER REACTIONS AT BASE:
DOWN: 84968 lb
UPLIFT: -73827 lb
SHEAR: 9117 lb

AXIAL 23517 lb
SHEAR 1592 lb
MOMENT 130342 lb-ft
TORQUE 677 lb-ft
30 mph WIND - 0.2500 in ICE

AXIAL 12146 lb
SHEAR 14844 lb
MOMENT 1166739 lb-ft
TORQUE 6751 lb-ft
REACTIONS - 85 mph WIND

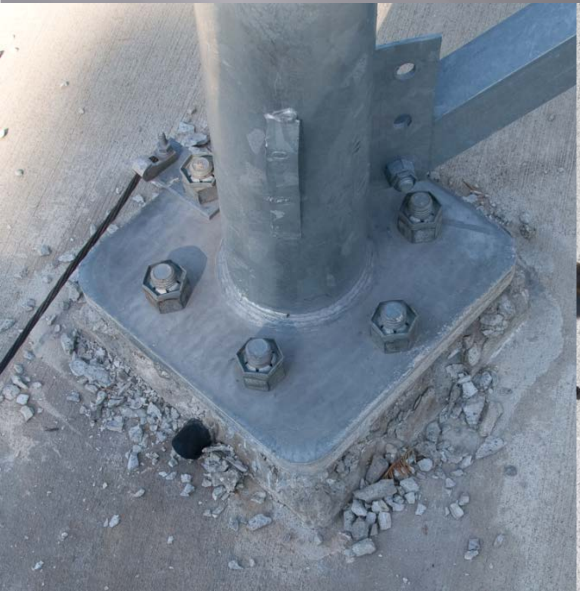
Job: **152-ft SS**		
Project: **Proposed V=85 mph, 30 mph with 1/4" Ice (3 sec Gus**		
Client:	Drawn by:	App'd:
Code: TIA-222-G	Date: 08/05/08	Scale: NTS
Path:		Dwg No. E-1

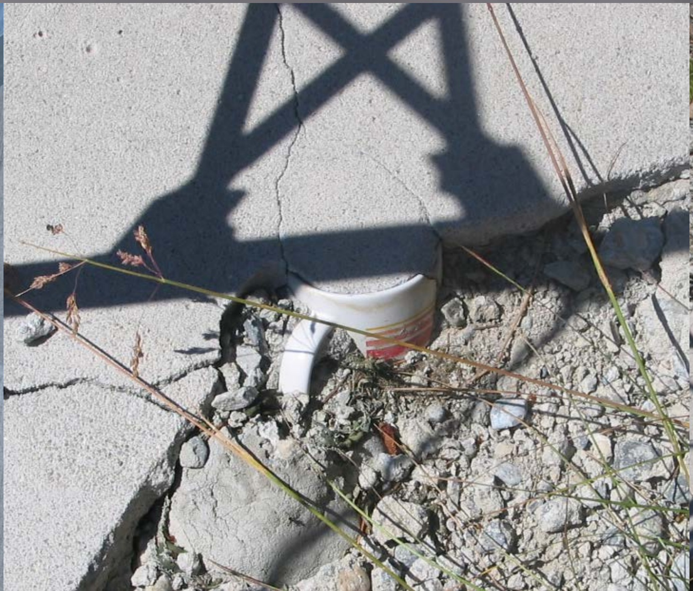
- Mechanical and Civil Engineers
- State Registered Professional Engineers (PE)
- Specialized Software
- Work closely with Tower Manufacturers
- Work closely with Architect and Landscaping Firms
- Must be familiar with wireless technology concerns
- Also local regulations

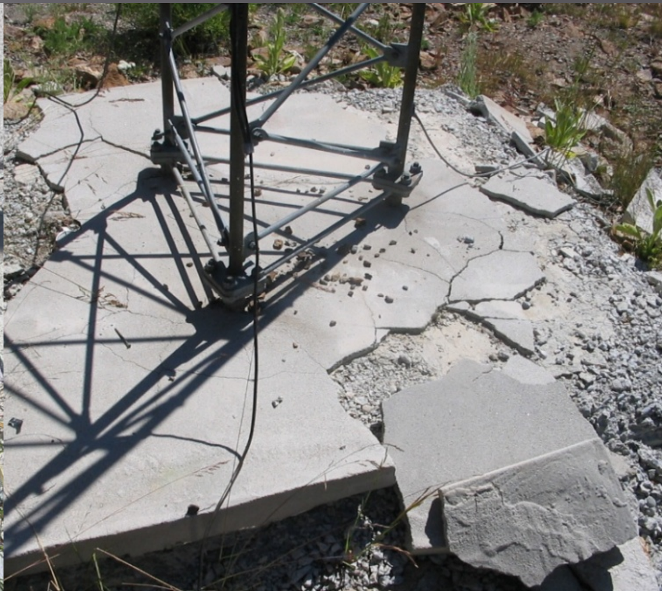
Towers

Field Survey and Tower Inspections sometimes yield surprising finds….

The effects of time, weather, cyclic stress, construction quality yield a finite lifetime for towers



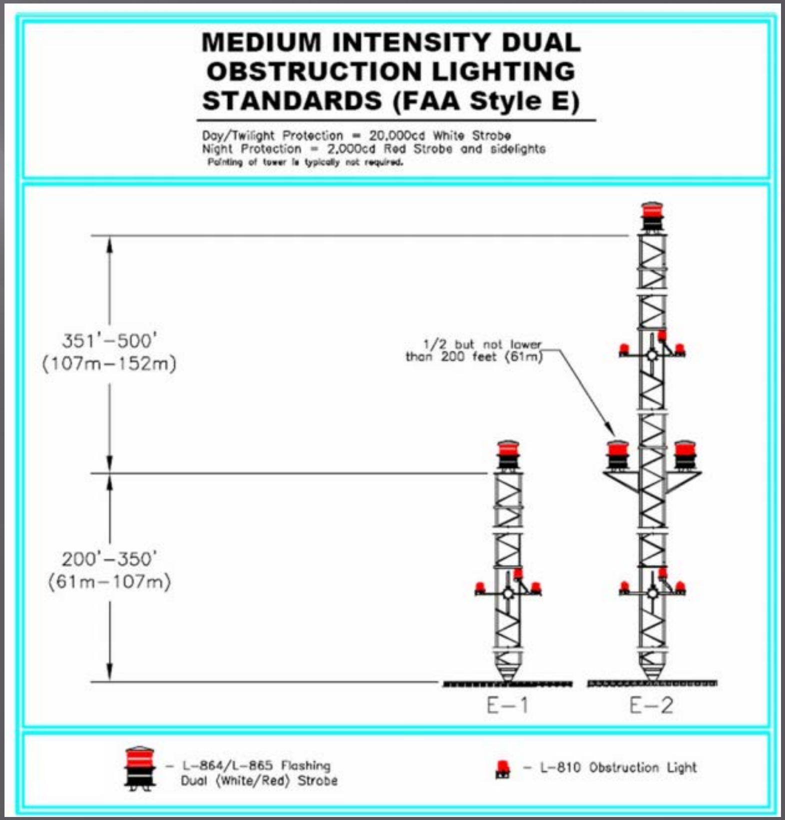


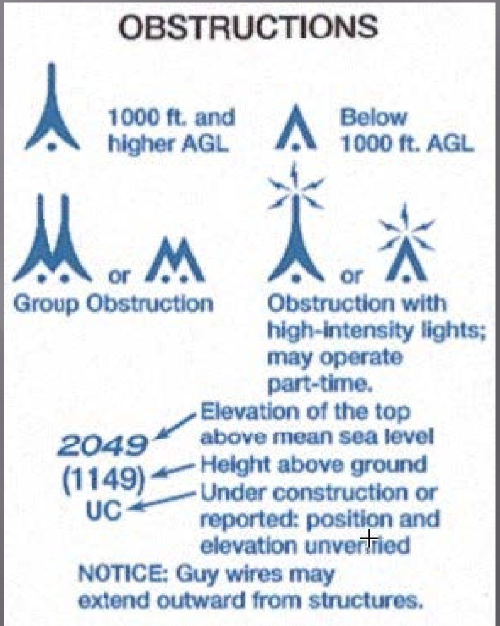


Towers

Tower height or location may evoke FAA requirements for marking, lighting and potentially - addition to aeronautical charts

- greater than 200 ft. AGL (remember 180′ + 25′ omni = 205′)
- less than 3 NM from established reference point of airport
- For each additional NM from airport, add 100 ft. height limit up to 500 ft.


MEDIUM INTENSITY DUAL OBSTRUCTION LIGHTING STANDARDS (FAA Style E)
Day/Twilight Protection = 20,000cd White Strobe
Night Protection = 2,000cd Red Strobe and sidelights
Painting of tower is typically not required.
351′–500′ (107m–152m)
200′–350′ (61m–107m)
1/2 but not lower than 200 feet (61m)
E–1
E–2
– L–864/L–865 Flashing Dual (White/Red) Strobe
– L–810 Obstruction Light


OBSTRUCTIONS
1000 ft. and higher AGL
Below 1000 ft. AGL
or
Group Obstruction
or
Obstruction with high-intensity lights; may operate part-time.
2049
(1149)
UC
Elevation of the top above mean sea level
Height above ground
Under construction or reported: position and elevation unverified
NOTICE: Guy wires may extend outward from structures.

Towers

FCC enforces tower lighting requirements and will impose heavy fines for those systems that fail or if tower owners do not report failures to the FAA

- FCC registered antenna structure owner, shall observe tower light system at least once every 24 hours, visually or by automatic indicator.
- Owner shall provide and properly maintain an automatic alarm system designed to detect failure of any such antenna tower light.
- The owner shall report immediately (or within 30 minutes of antenna tower light failure) to the nearest Flight Service Station or FAA office.

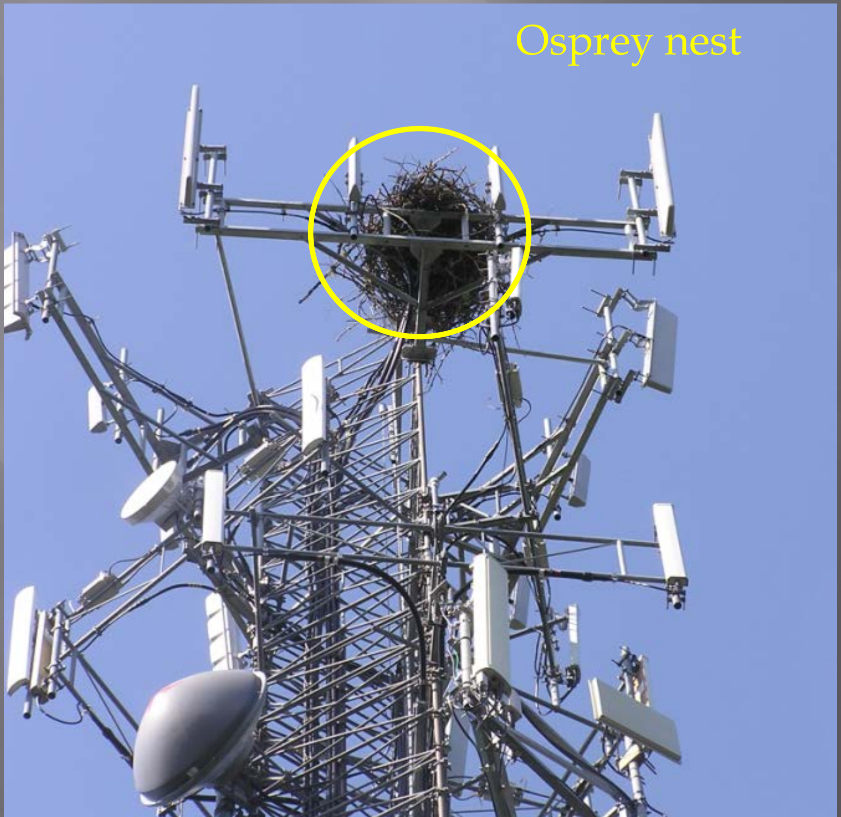
Towers

- Long-term investment and potential liability for agencies
- Must undergo periodic inspections
- Maintenance of materials
- Climb certification and climb gear mandatory

Towers

Contractual Obligations

- Lease agreements
- Co-locations with other PS agencies or Carriers (IMD Studies)
- Even wildlife protection !



Towers

- Climb certification for techs
- Climb gear mandatory
- OSHA states if employee climbs >6ft, must be trained and certified in fall protection

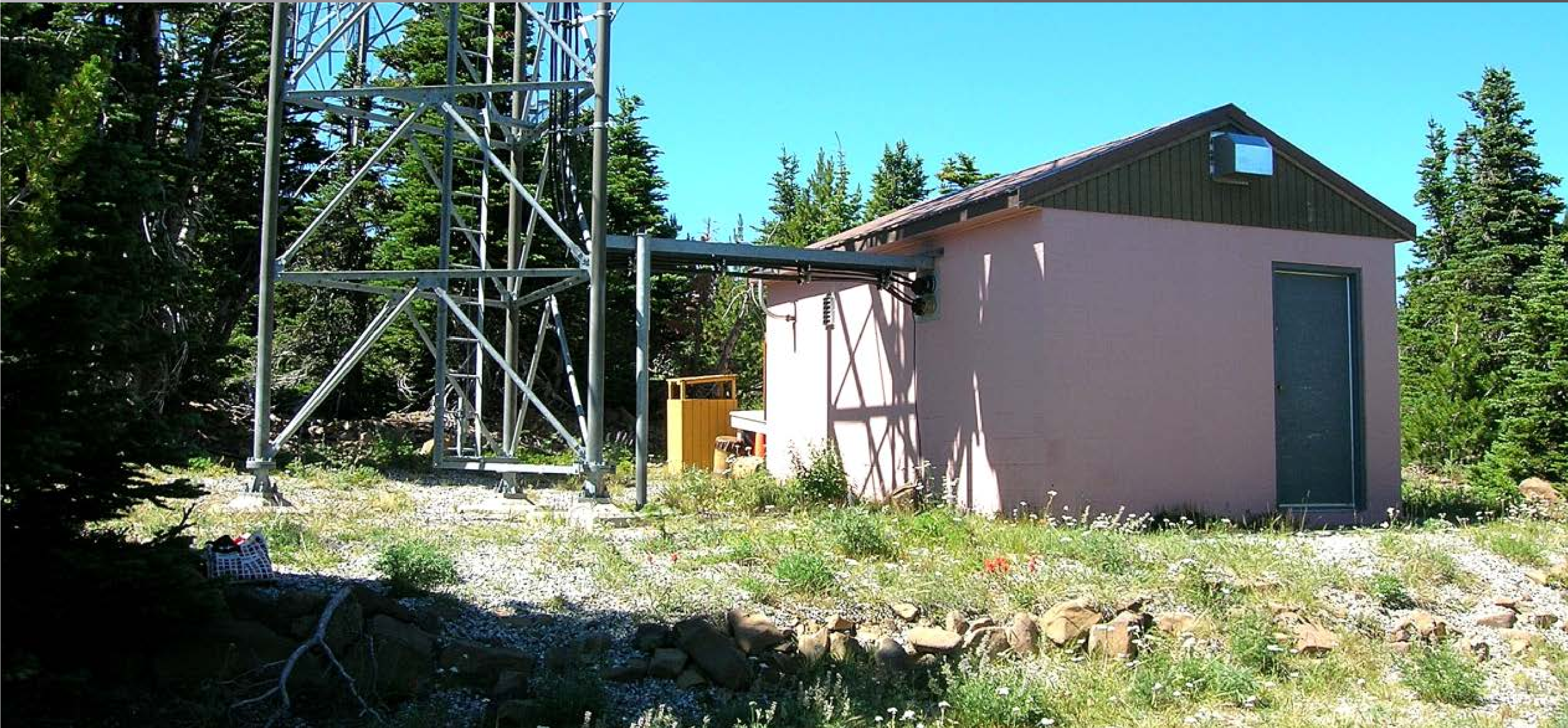
Towers

Tower Site Concerns

- Security and Tower Ladder Access devices
- Copper theft out of control, using *distractor* copper
- IP Cameras with DVR's and motion detection common
- Liability concerns (on-site fatalities or injuries)

Towers

Can you identify areas for safety and security improvement?

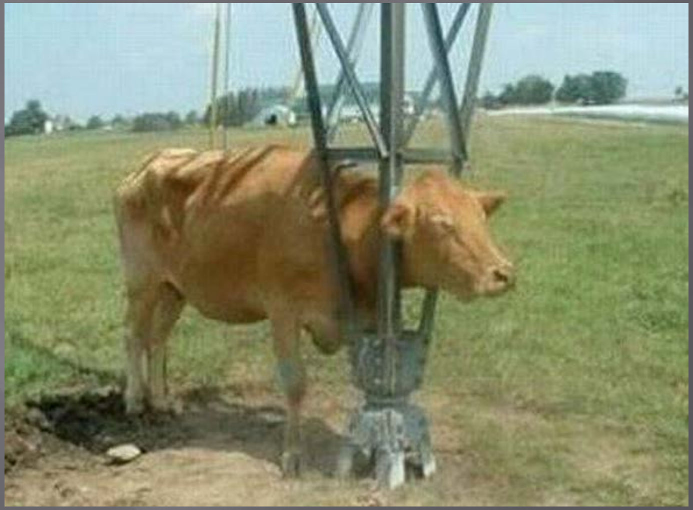


Towers

Yes, there is a limit what you can plan for…

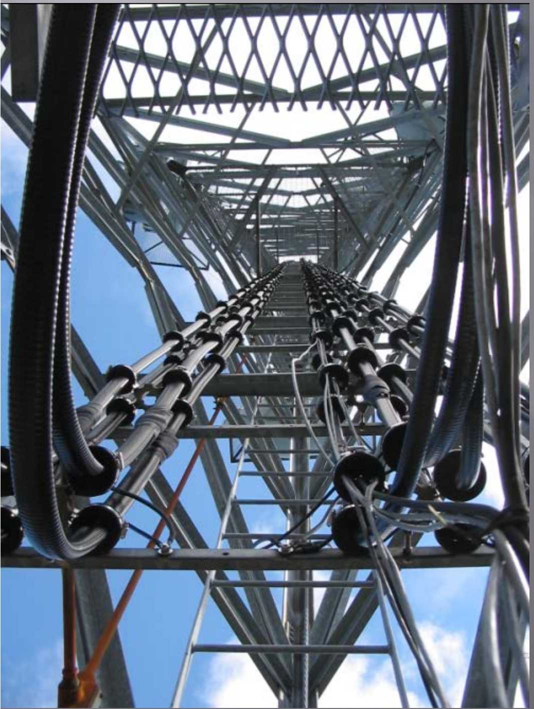
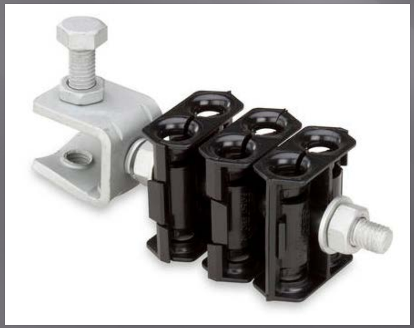
This photo shows which of the following ?

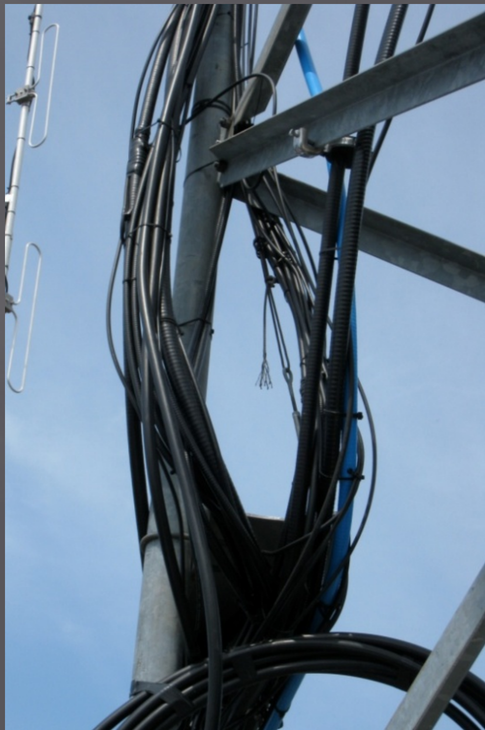
- 1 HP (CP) tower rotator demo at Dayton Hamvention 2012
- 4-point ground system
- Bovine security system (beware of attack heffer)
- SPCA donation drive poster
- Wisconsin Diary farm Wireless Milking Station



Towers

- All appurtenances (antennas, cables, dishes,) should use purpose-designed mounting hardware
- Cable clamps must be for the OD of the cable used
- Goal is to address strain, stress, bends, kinks and chaos
- Nylon ties are unacceptable except for very limited interior applications



Standby Power Design

Sites must survive off-grid several days to weeks

There are short-term and long-term standby power solutions

- Battery Banks -48 VDC, 24 and 12 VDC
- Generators – Diesel, Propane and LP
- UPS (more common for IT applications)
- Hydrogen Fuel Cell

Standby Power Systems

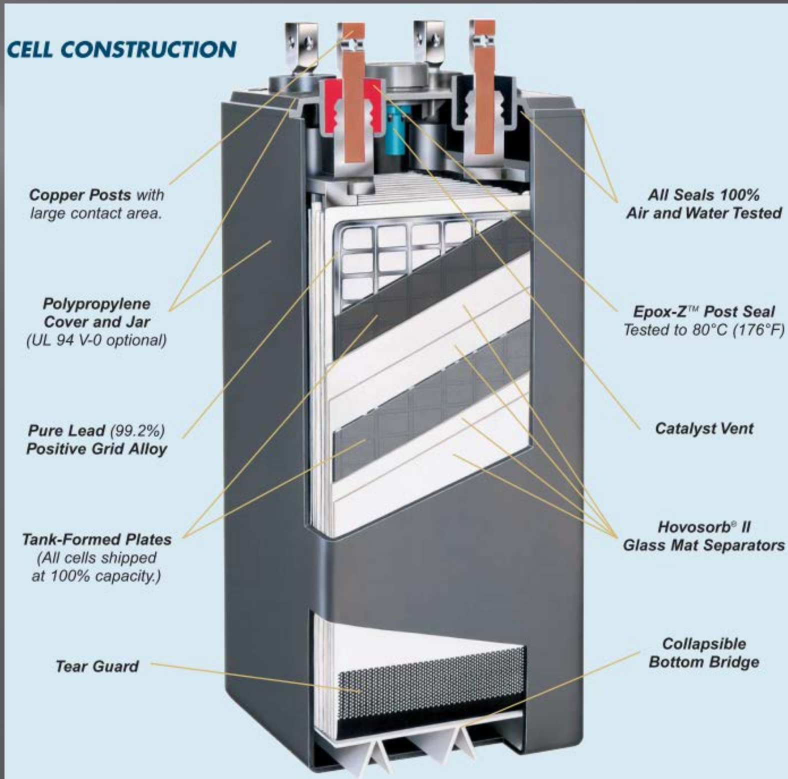
Battery Banks

- Sealed Lead-acid still common (maintenance and venting requirements)
- Finite life expectancy (now up to 15 - 20 years)
- May affect shelter design due to weight and floor loading
- Many sites are ‘floated’ 100% on batteries
- - 48 VDC the current standard

Standby Power Systems

Batteries

- Higher grade than automotive
- Typically available in 4V, 6V, 8V and 12V cells
- Assembled in modules (2, 3, 4, or 6 cells/module)
- 250 lb. – 700 lb./module !


CELL CONSTRUCTION
Copper Posts with large contact area.
Polypropylene Cover and Jar (UL 94 V-0 optional)
Pure Lead (99.2%) Positive Grid Alloy
Tank-Formed Plates (All cells shipped at 100% capacity.)
Tear Guard
All Seals 100% Air and Water Tested
Epox-Z™ Post Seal Tested to 80°C (176°F)
Catalyst Vent
Hovosorb® II Glass Mat Separators
Collapsible Bottom Bridge

Standby Power Systems

- DC - DC Conversion is often used
- -48 VDC now common for base station primary power
- Load rating important to allow charge and full load reserve capacity

Standby Power Systems

Common Component Terms

- **Rectifier** – your DC power supply and battery charger
  primary power

- **Converter** – typically DC-DC conversion (ex. -48 VDC to 12 VDC)

- **Inverter** – DC to AC pure sine wave inversion
  (critical AC site components that are not heavy loads are often run off of inverters, exceptions to this are HVAC)

Standby Power Systems

Generators

- Rating important – want to run at 75% of load ideally
- Day tank and extended run tanks
- Modern design with remote management via IP and alarms via SNMP traps

Cummins Onan, Kohler and Generac are common for PS Sites

Standby Power Systems

Automatic Transfer Switch (ATS)

- Automatically switches load between line and generator during utility main failure
- Also allows remote activations of Generator and system monitoring

Typical ATS transfer sequence:

Senses interruption of utility power
Sends start signal to Generator
Senses Generator power is available
Transfers load to Generator
Senses return of utility power
Retransfers load to utility
Sends stop signal to Generator

Standby Power Systems

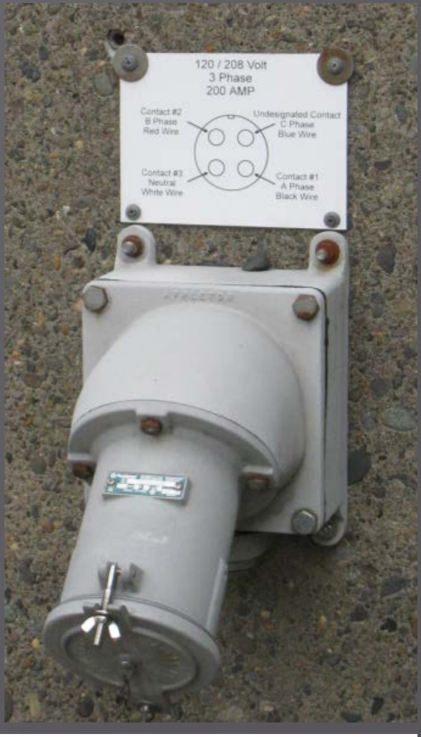
Fuel

- Diesel – common but also requires fuel conditioning to prevent. May not be approved for use at all location due to spill/contamination concerns
- LP and Propane – determination of gaseous or liquid form determined on temperature band of site location
- Capacity determined by run time needed based on site accessibility

Standby Power Systems

Fuel

- Site access reasonable all year ?
- Portable (towed) generators also an option



Standby Power Systems

Your mileage may vary, so to speak….

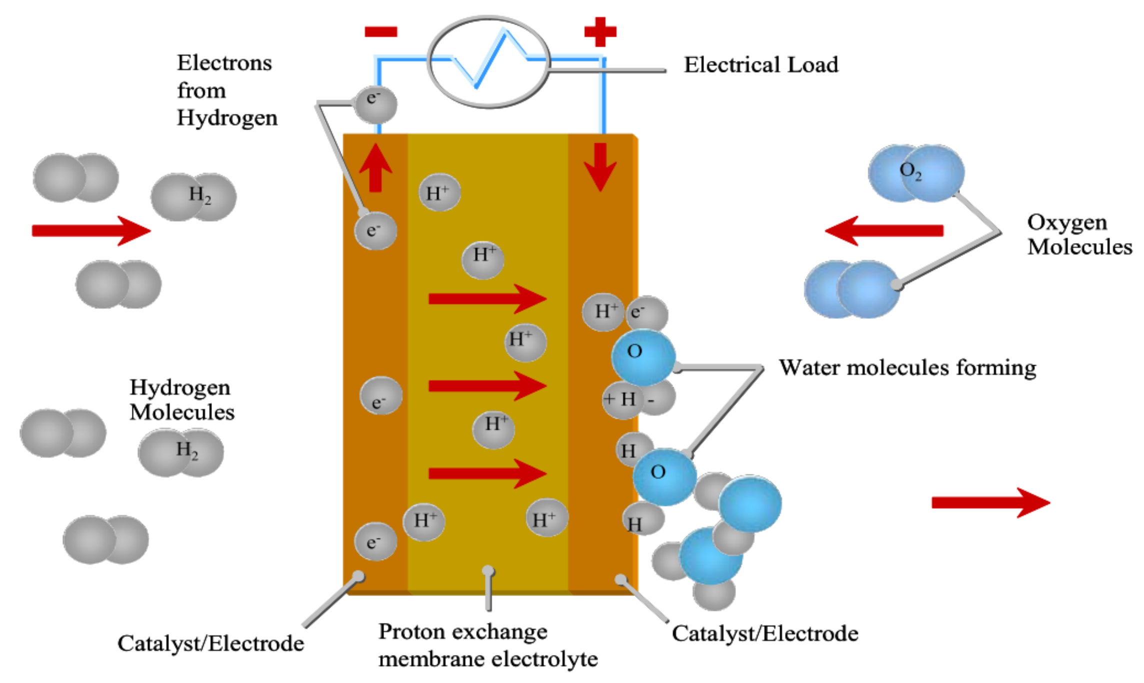
Standby Power Systems

- Generators require:
  - inspection
  - maintenance
  - load testing
  - ATS testing
  - fuel conditioning

Standby Power Systems

Latest Technology - Hydrogen Fuel Cells

- Converts chemical energy of a fuel and an oxidant in to electricity
- Battery with a PEM (Proton Exchange Membrane)



Standby Power Systems

- DOE encouraging use of this technology
- Not instantaneous power 30 secs. – 2 minutes
- Clean emission – water vapor
- Modular Replacement Cartridges, typically 50 watt – 20 kW range
- Fuel Cell Tax Incentive
- Hydrogen actually less dangerous than other fuel forms

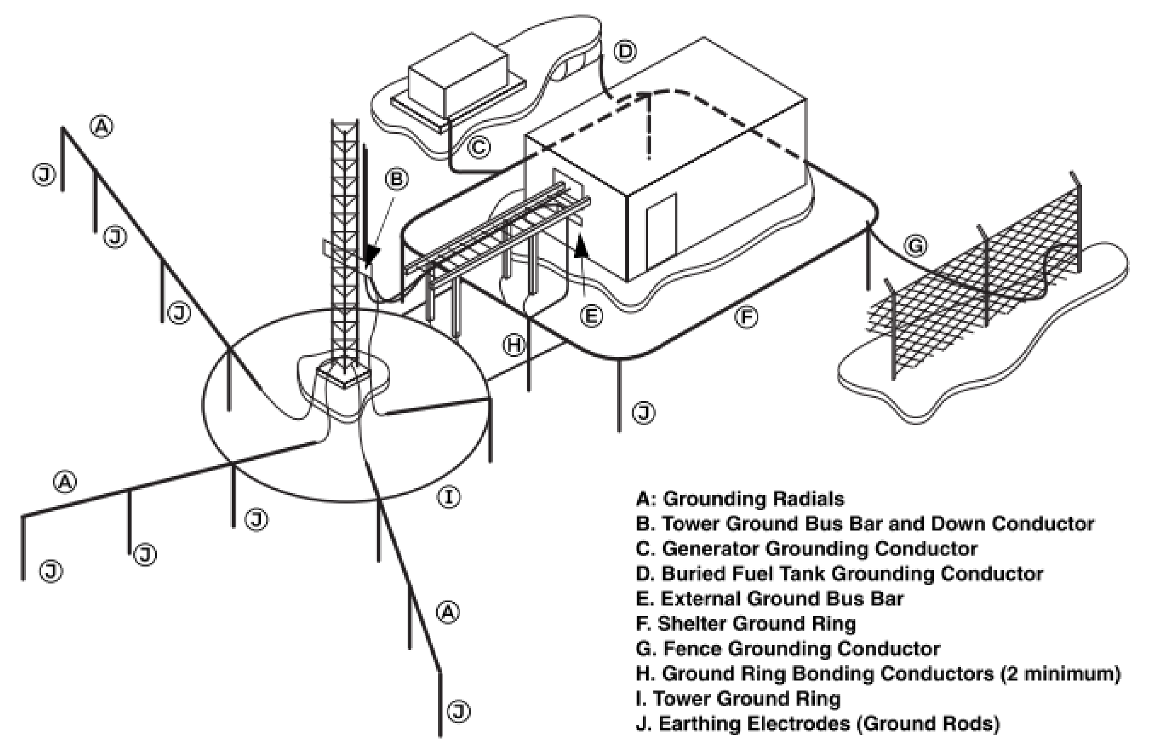
Site Grounding

- No standards in the old days – lucky if you met NEC
- Poor grounding is culprit of many problems
- Current industry standard is Motorola R56

Site Grounding

Motorola R56 Standards & Guidelines for Comm Sites

- Site Design & Development
- Grounding and Bonding techniques
- Best installation practice and techniques


A: Grounding Radials
B. Tower Ground Bus Bar and Down Conductor
C. Generator Grounding Conductor
D. Buried Fuel Tank Grounding Conductor
E. External Ground Bus Bar
F. Shelter Ground Ring
G. Fence Grounding Conductor
H. Ground Ring Bonding Conductors (2 minimum)
I. Tower Ground Ring
J. Earthing Electrodes (Ground Rods)

Site Grounding

Specialized tools, components and techniques

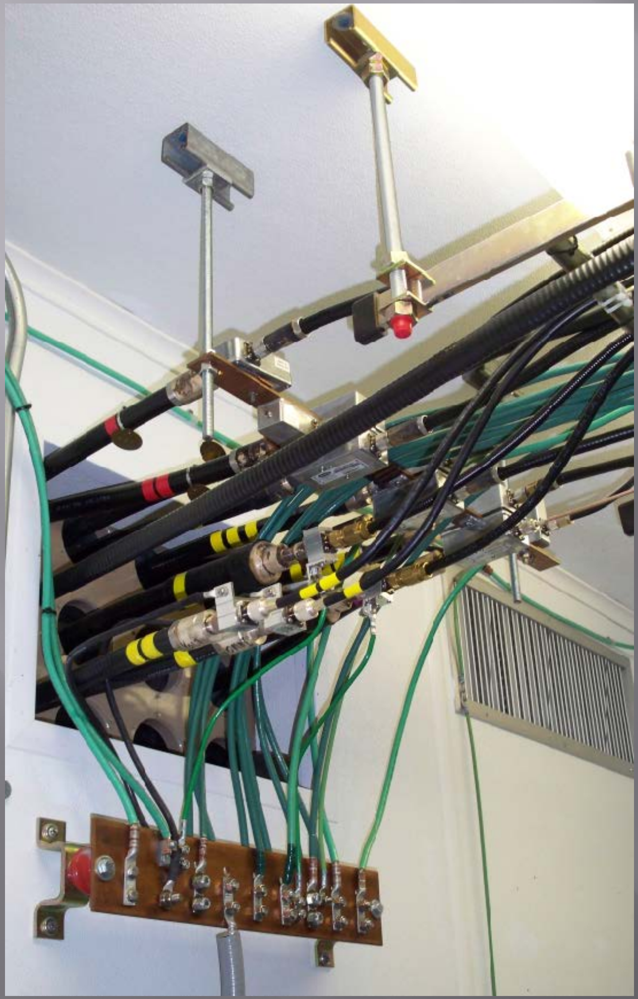
- 2-ton, irreversible compression clamps
- C-type compression taps
- 1 and 2 hole compression lugs
- Manual, electric and hydraulic tools

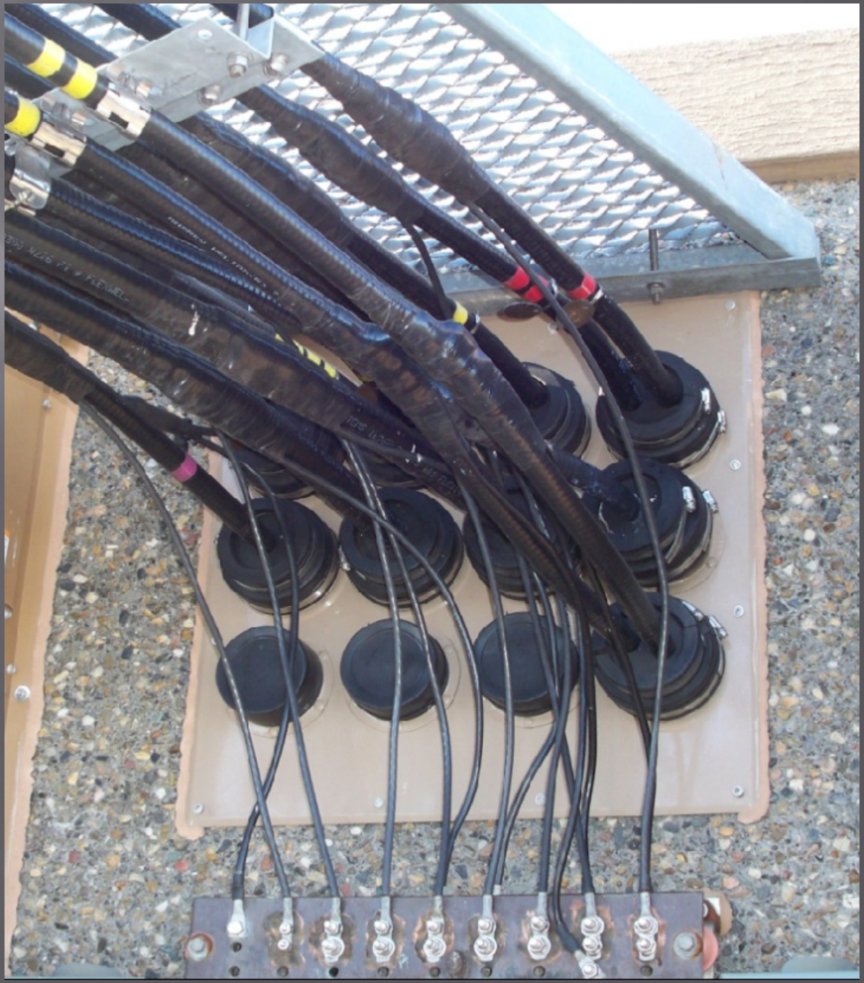
…and skill is using these

R56 Installer & Auditor Certification

Site Grounding

Panel entry port and grounding point (busses)

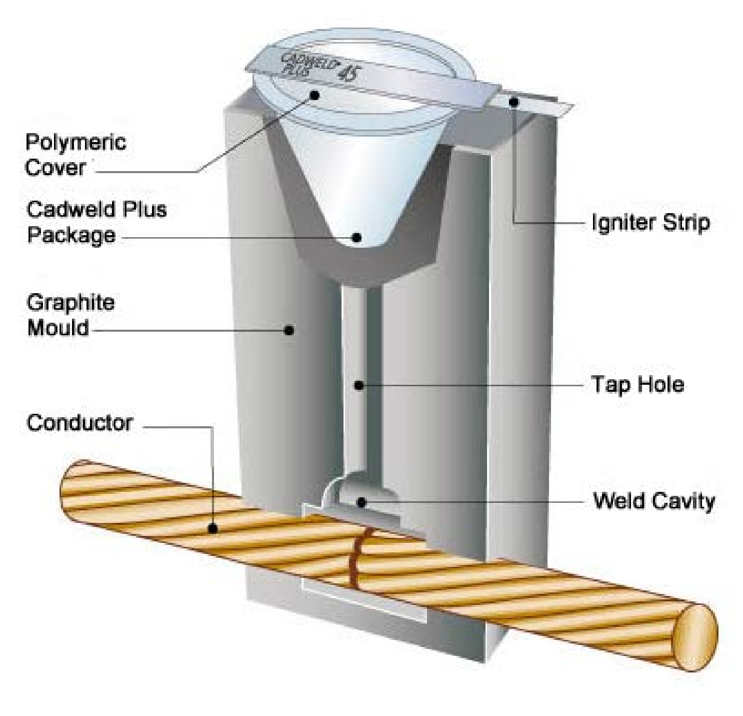


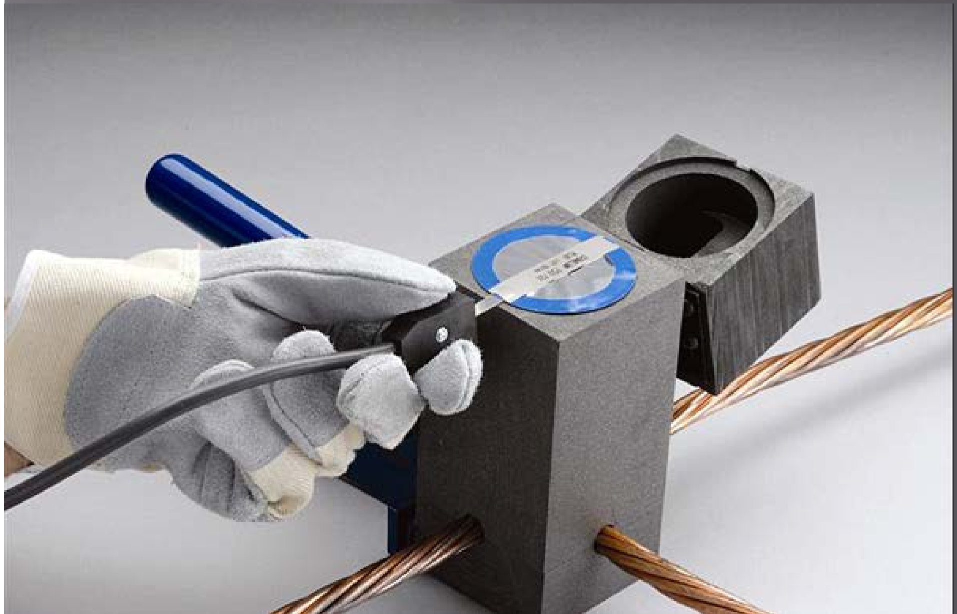


Site Grounding

Exothermic Welding Technology

- Higher mechanical strength than other weld types
- Excellent corrosion resistance
- Highly stable if subject to repeated short-circuits
- No increased electrical resistance over installed lifetime

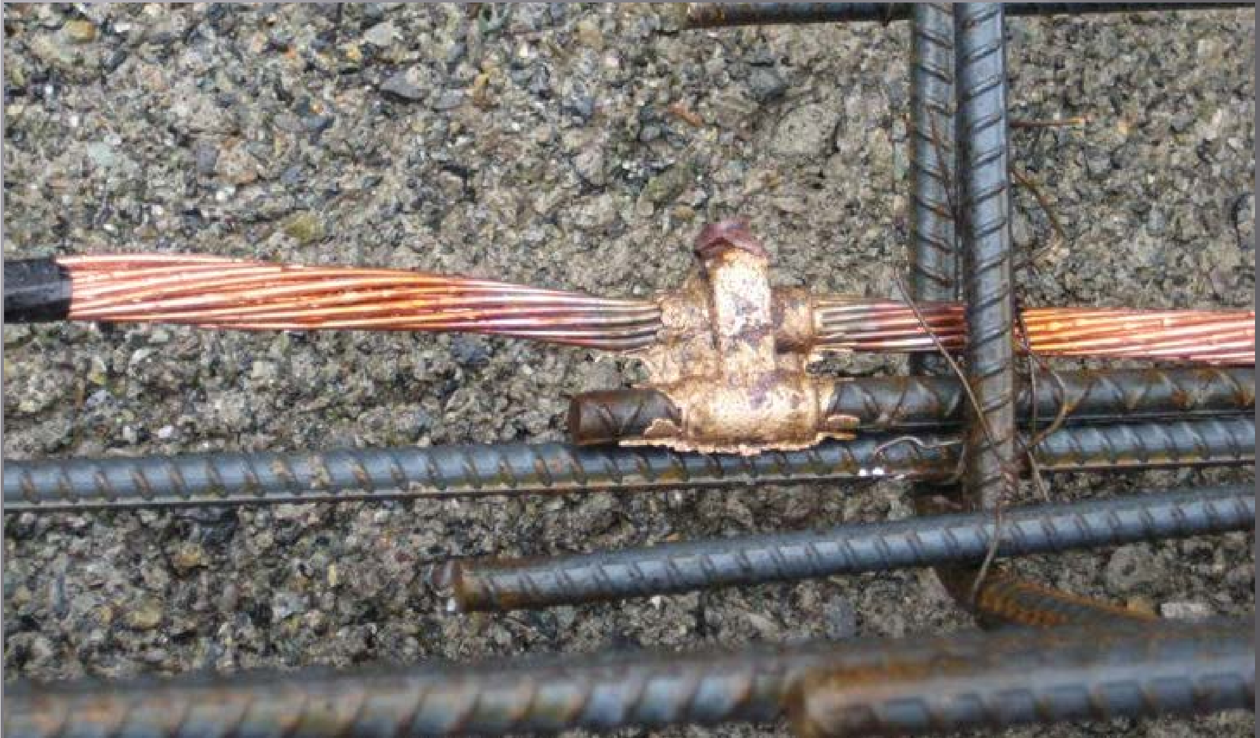


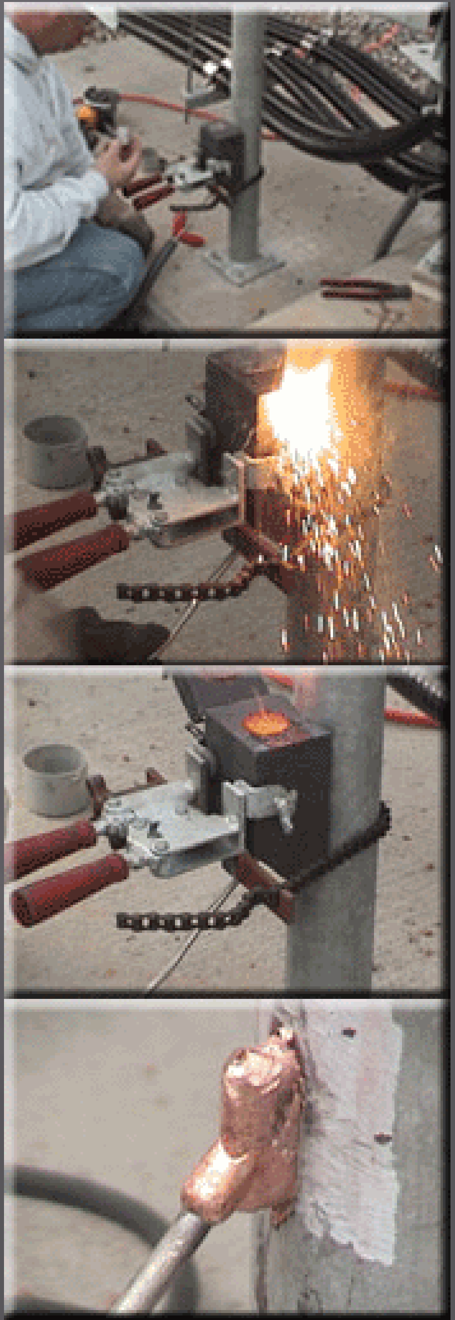


Site Grounding

Exothermic welds (Cadweld™) used for buried grounds and exterior grounding

- Exothermic reaction best used for Cu-Cu or Cu-Fe bonds



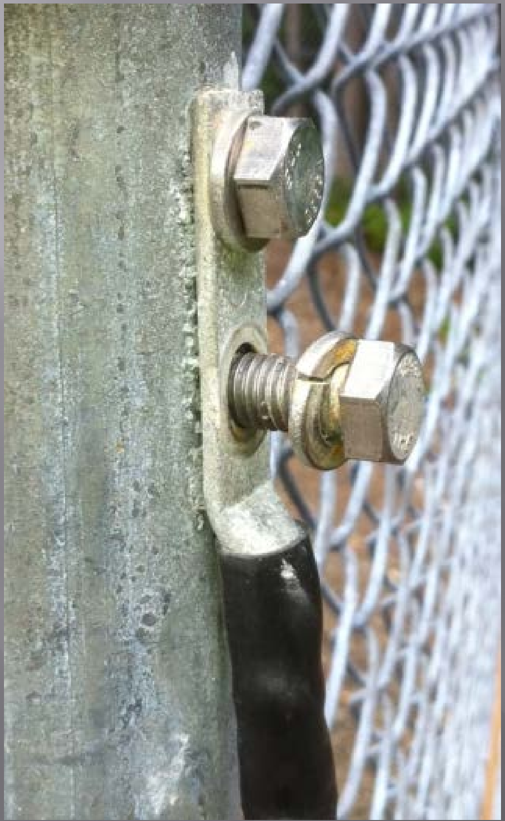


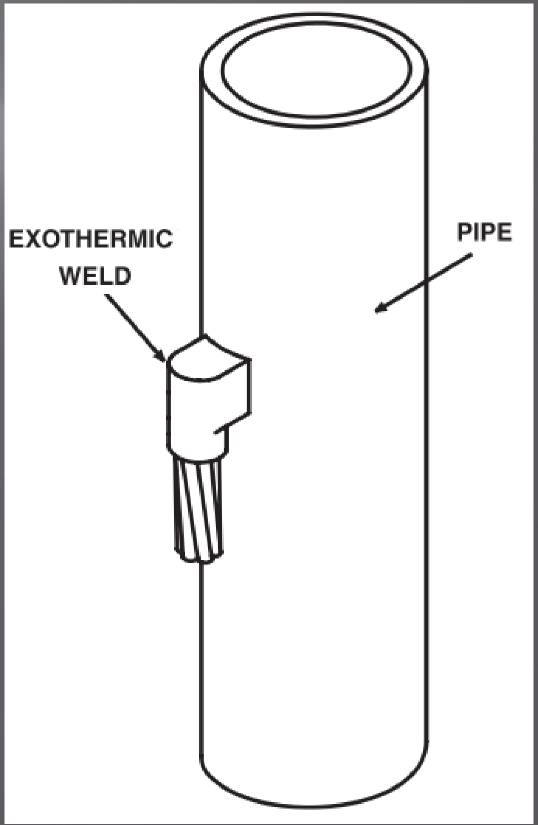
Site Grounding

R56 Grounding Audit…

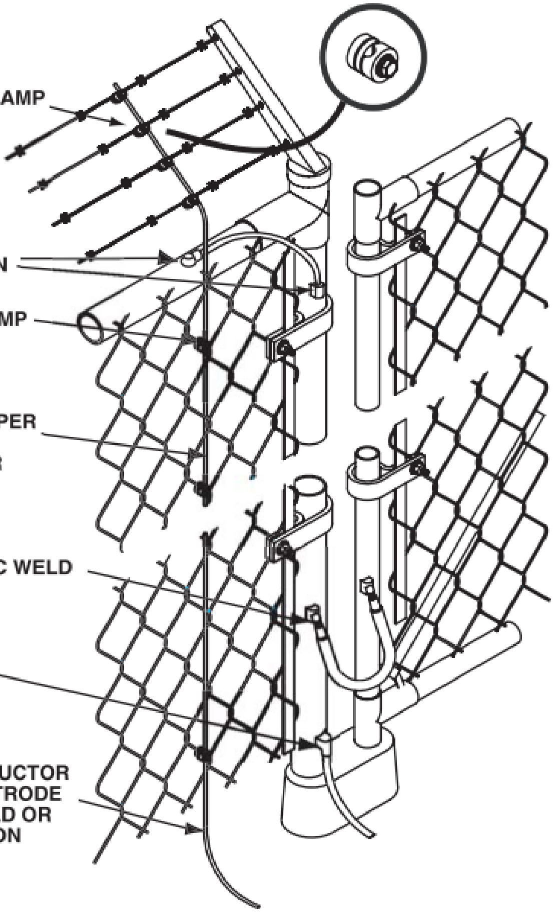
Pass / Fail ?

We'll come back to this later….





R56



DETERRENT WIRE GROUNDING CLAMP

EXOTHERMIC WELD CONNECTION

FENCE FABRIC GROUNDING CLAMP

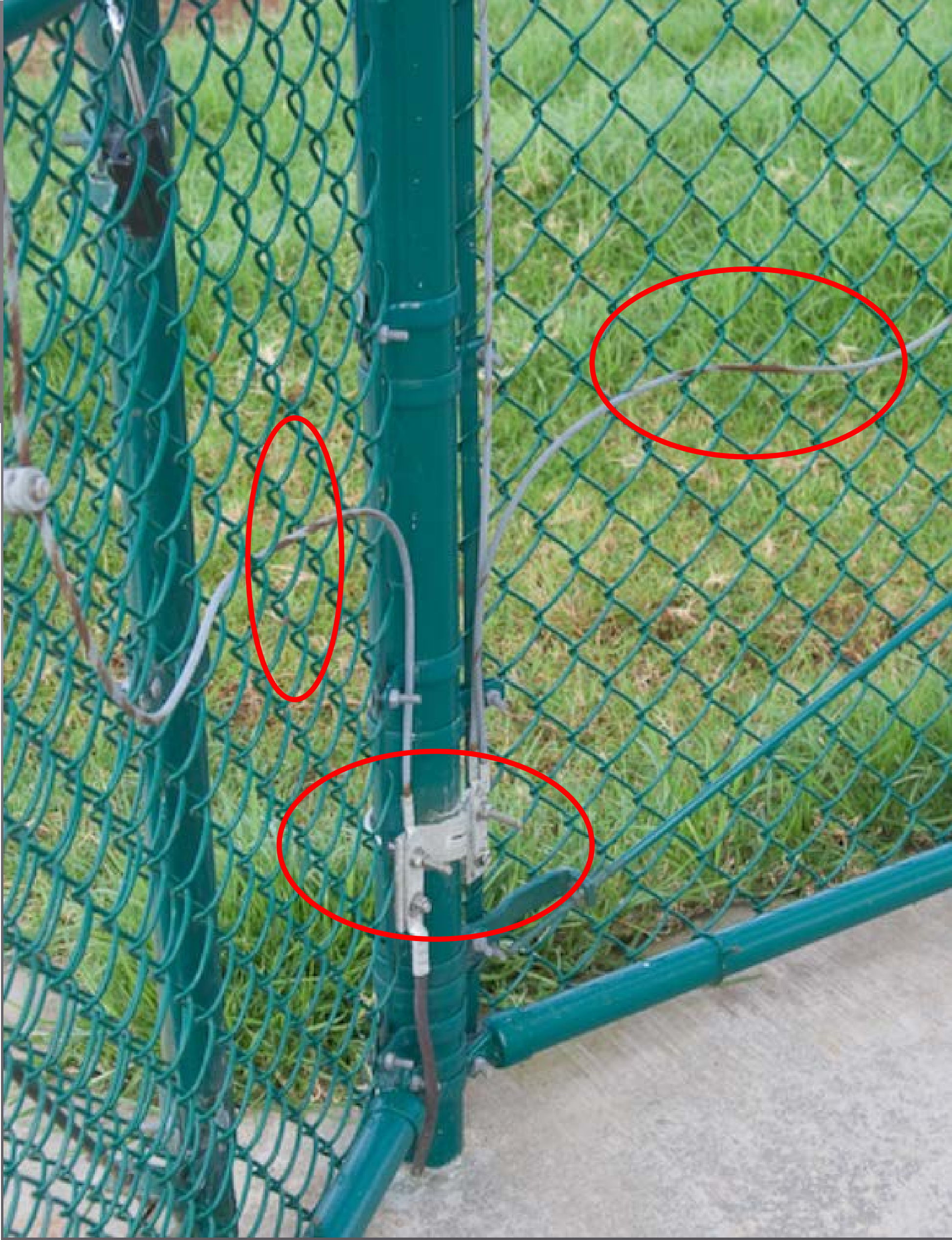
SOFT DRAWN TINNED SOLID COPPER CONDUCTOR BONDING FENCE FABRIC TO GROUND CONDUCTOR

GATE JUMPER WITH EXOTHERMIC WELD

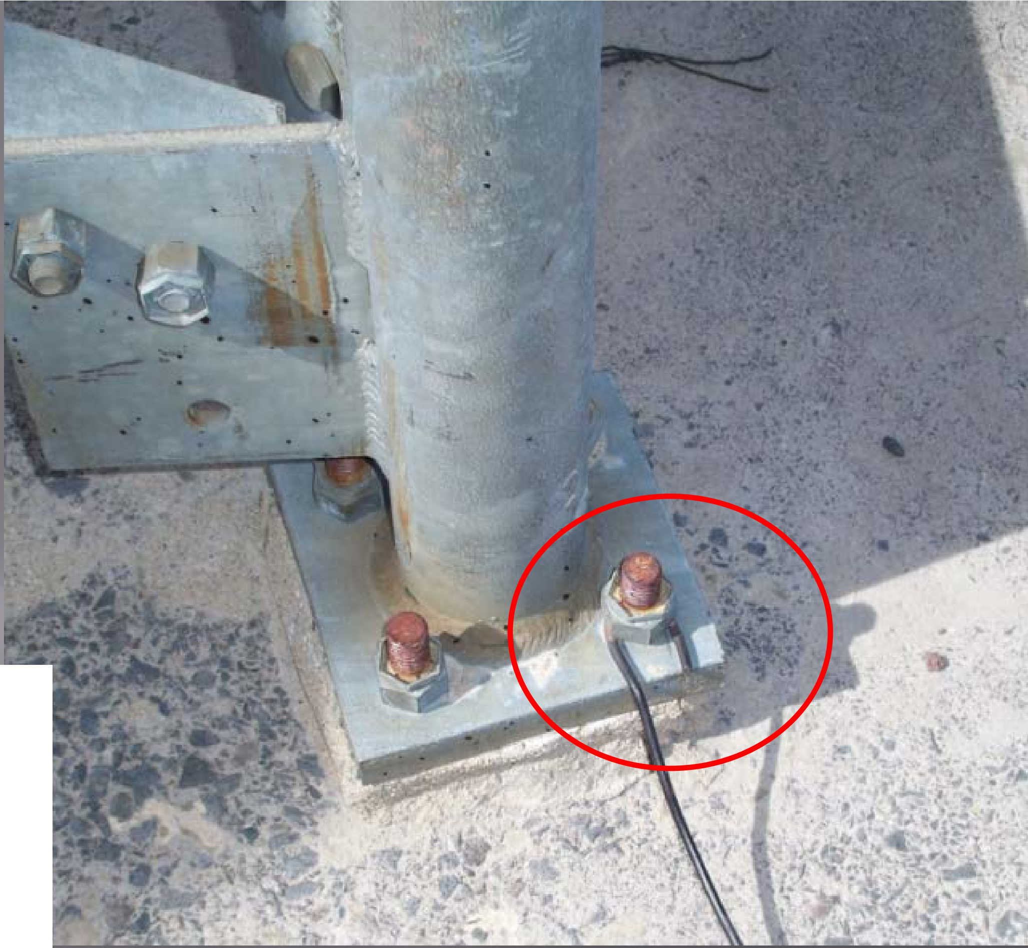
GROUND CONDUCTOR WITH EXOTHERMIC WELD

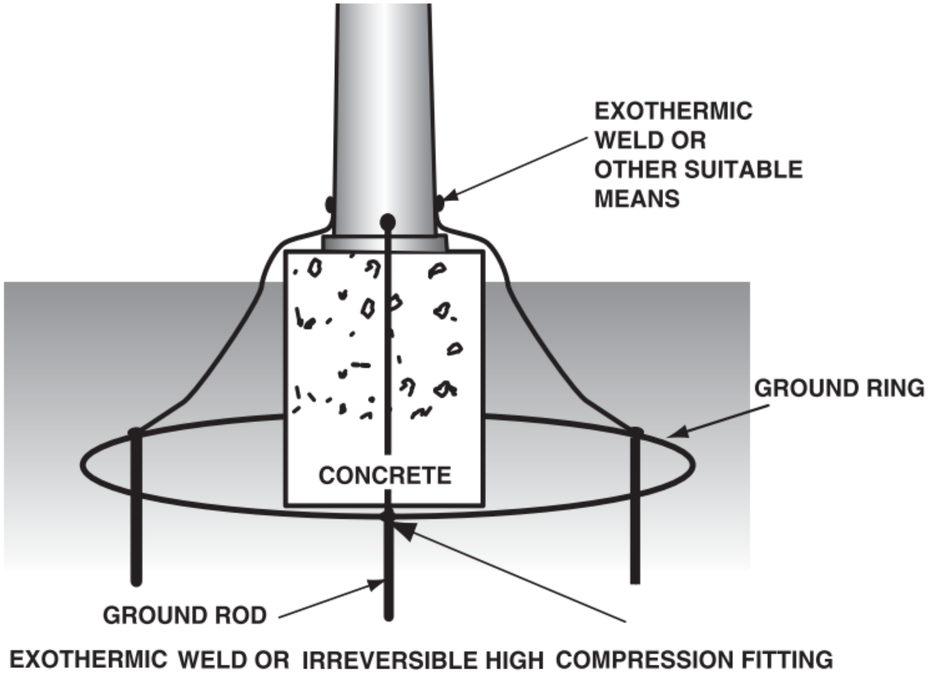
CONNECT FENCE BONDING CONDUCTOR TO EXTERNAL GROUNDING ELECTRODE SYSTEM USING EXOTHERMIC WELD OR IRREVERSIBLE HIGH-COMPRESSION FITTING

Fence Fabric and Deterrent Wiring Bonding Example



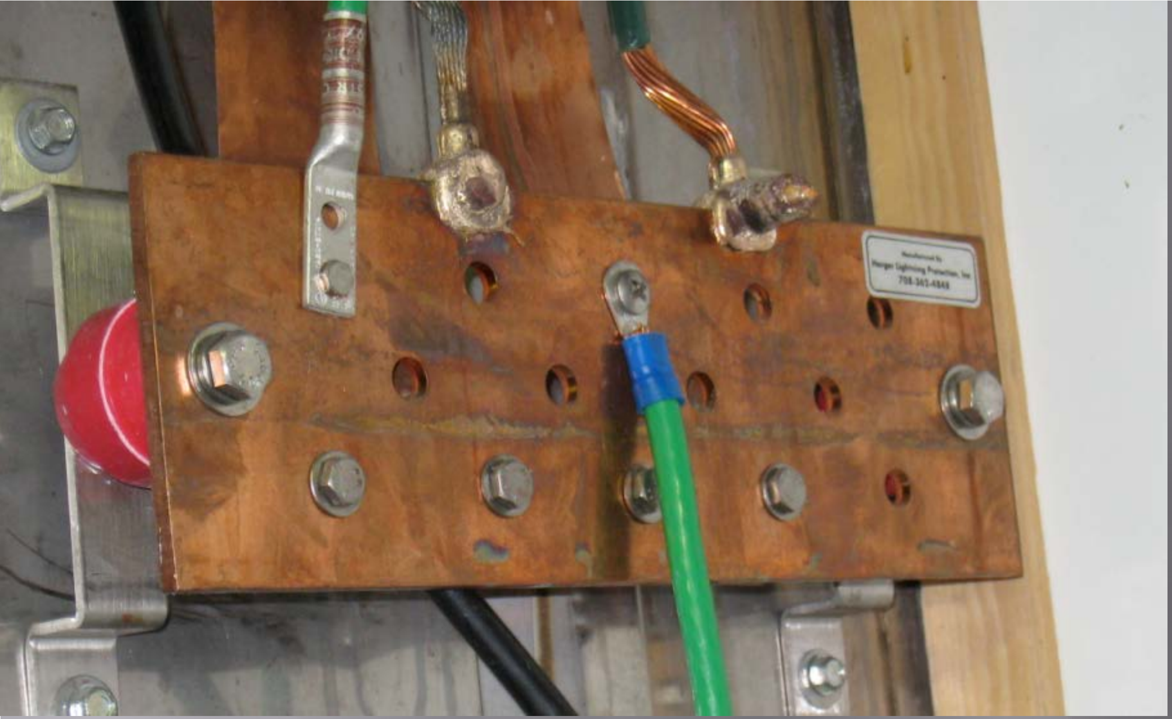
Unbelievable, but true




EXOTHERMIC WELD OR OTHER SUITABLE MEANS
GROUND RING
CONCRETE
GROUND ROD
EXOTHERMIC WELD OR IRREVERSIBLE HIGH COMPRESSION FITTING

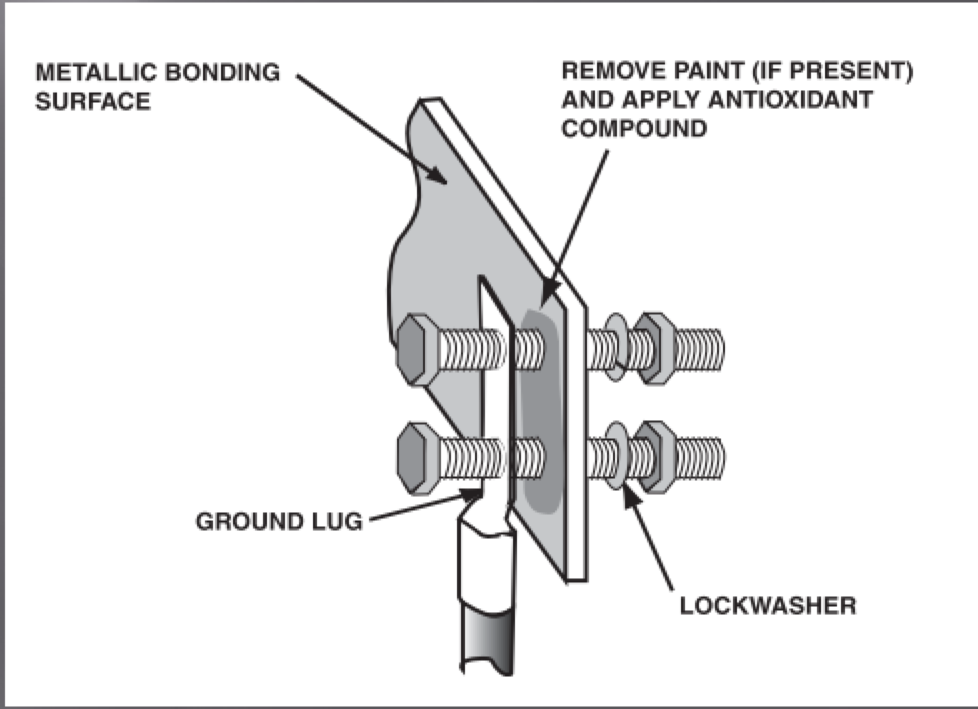
EXAMPLE OF TOWER GROUNDING

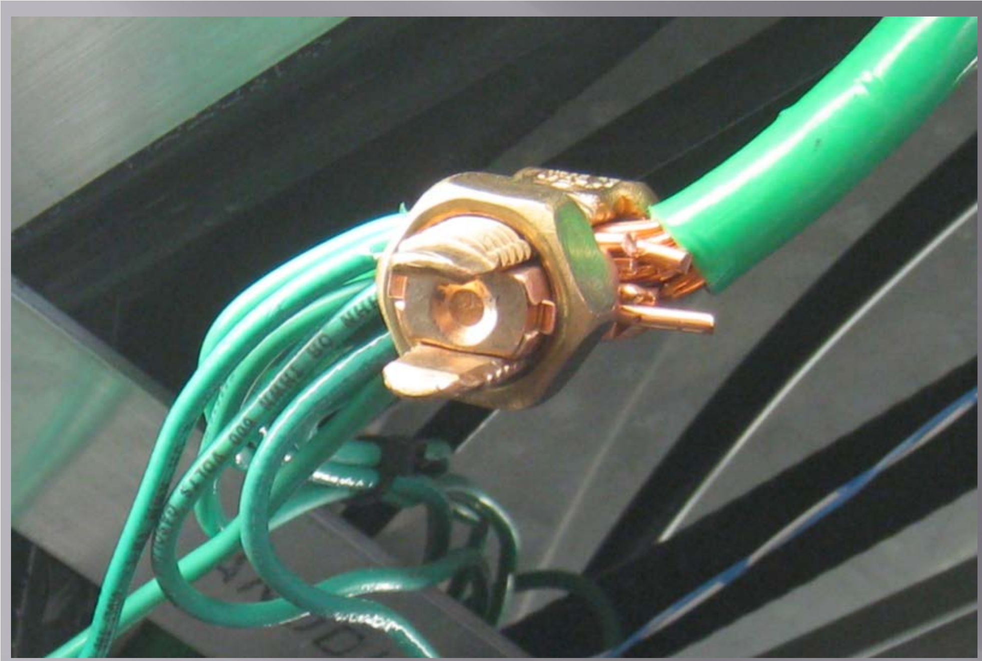
R56



Where do you begin …?

R56



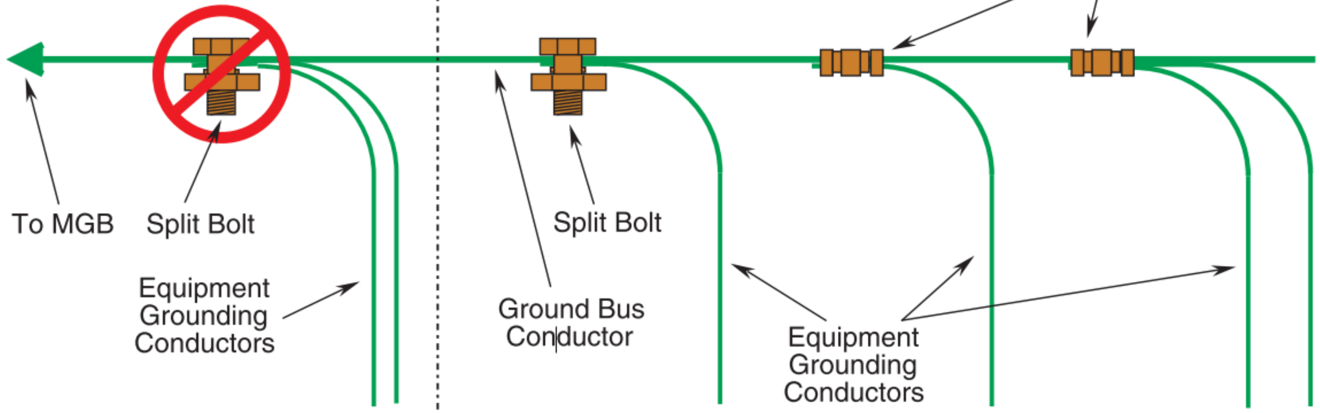


R56

UNACCEPTABLE METHOD
unless the split bolt is listed for the size and number of conductors to be connected.

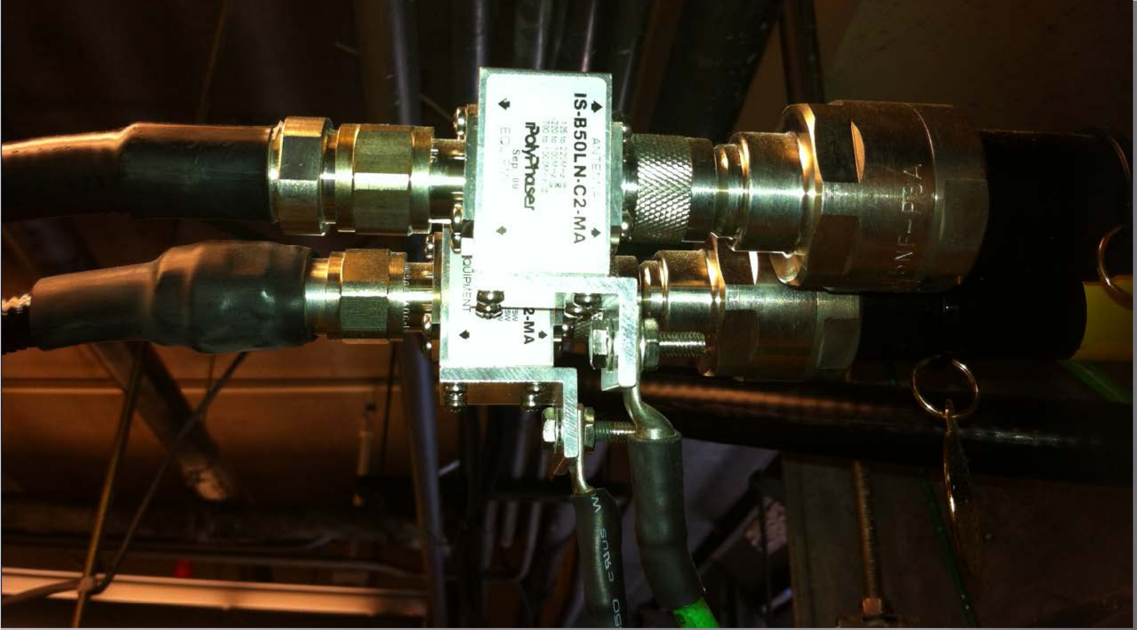
ACCEPTABLE METHODS

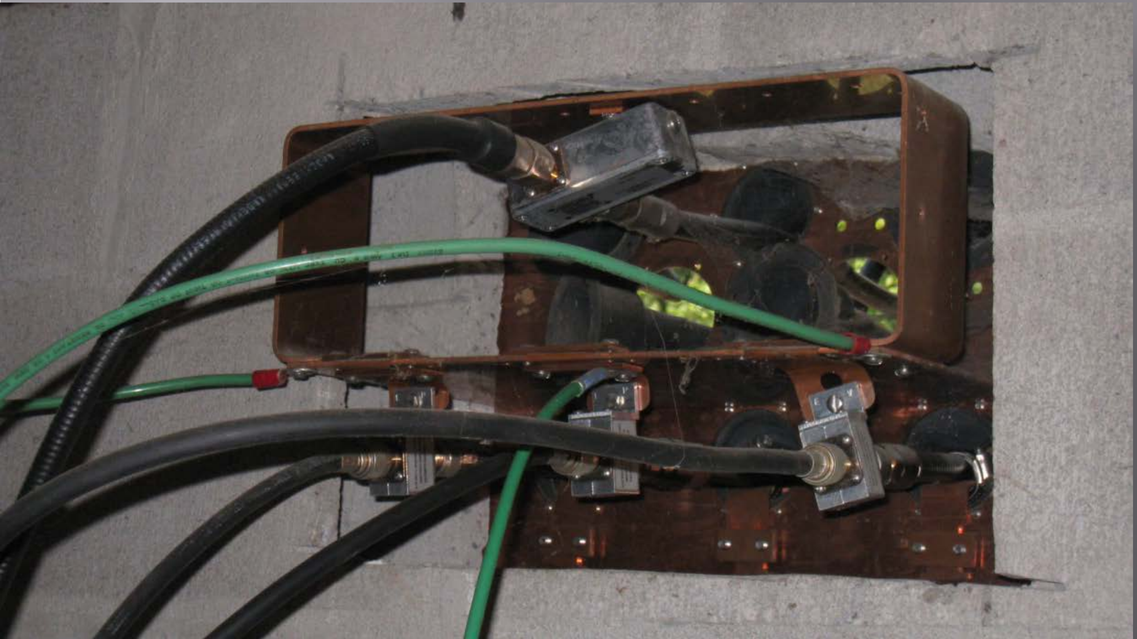
Irreversible crimp connection (must be listed for multiple connections)

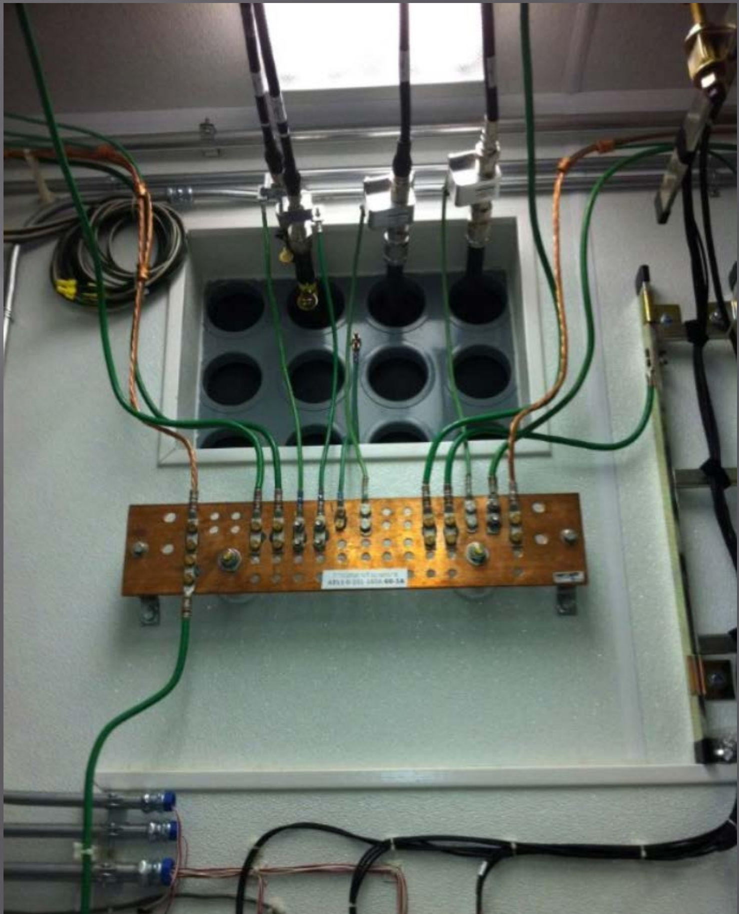

To MGB
Split Bolt
Equipment Grounding Conductors
Split Bolt
Ground Bus Conductor
Equipment Grounding Conductors

NOTE: Route all conductors toward the MGB.

BONDING TO GROUND BUS CONDUCTOR


ANTENNA
IS-B50LN-C2-MA
PolyPhaser
Sep 09
EQUIPMENT
2-MA





Site Grounding

Why the obsession with grounding…?

- Everyone thinks lightning – and that is correct
- But there’s another important reason….

Site Grounding

Passive Inter-Modulation (PIM) Interference

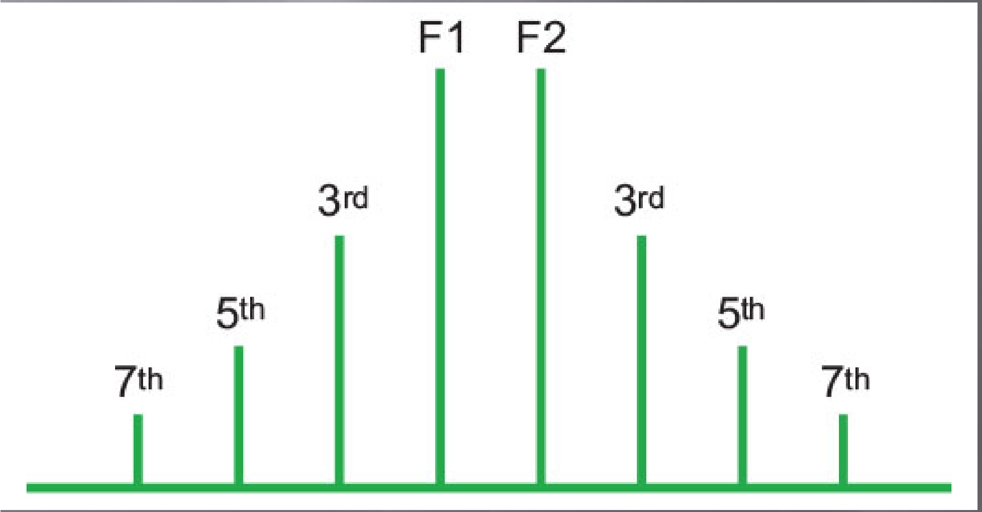
- Result of multiple RF carriers forming spurious mixing products across non-linear junction or surfaces, typically at high Tx power levels
- PIM can reduce local receive sensitivity as well as other nearby receivers
- Digital modulation used in P25 systems make PIM an issue due to higher peak instantaneous power (PIP) levels produced by new TDMA format
- Caused on-site by…..
  - Poor connector assembly
  - Improperly torqued connectors
  - Scratches/oxidation/contamination on conducting surfaces
  - Poor quality of components or components that lack durability
  - Plating quality or improper plating thickness
  - Low quality or damaged cable assemblies, adapters, or connectors

Site Grounding

Passive Inter-Modulation (PIM) Interference

Simple formula to calculate PIM

- 3rd Order = 2F1 – F2 and 2F2 – F1
- 5th Order = 3F1 – 2F2 and 3F2 – 2F1
- 7th Order = 4F1 – 3F2 and 4F2 – 3F1



Site Grounding

Solution is Good Grounding, Good Construction Techniques and use of "PIM Rated" Components

- Now have Industry Awareness
- PIM Training and Certification
- Clean electro-mechanical installation practices
- PIM-Rated Connectors – "N" being replaced with "DIN"
- PIM-Rated Antennas
- PIM Testing Equipment

Microwave Transport

- Digital connectivity crucial for modern infrastructure
- Carrier leased lines (4W, 4W E&M) becoming obsolete
- “Internet” completely unacceptable
- Agency-owned microwave is primary transport
- Fiber optic used as backup

Microwave Transport

Why microwave…?

Transmission Technology	Reliable Distance	Degree of Control	Nature of Outages	Fixed Cost	Ongoing Cost
Leased Circuits	∞	Low	Damage, Carrier	Low	High
Fiber Optic	80 miles	Low-Med	Damage	High	Low
FSO mm Wave	1 mile	High	Atmospheric	High	Low
Microwave	50 miles	High	Atmospheric	High	Low

Microwave Transport

Microwave Transceivers

- Technology - TDM (circuit switched/T1) and IP
- Licensed FCC Part 101 and Unlicensed Spectrum

Time Division Multiplexing (TDM)

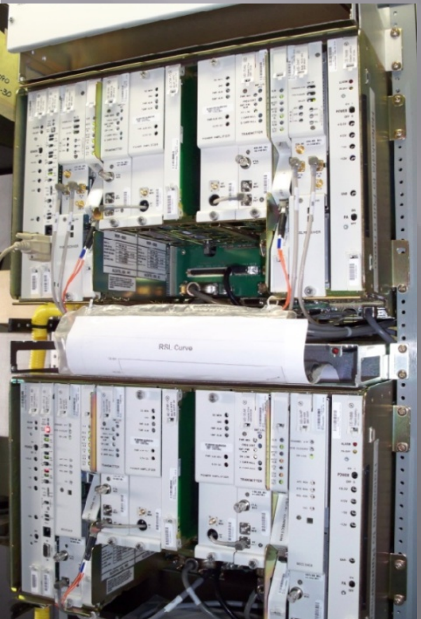
–variety of voice or data interfaces merged into single data connection

- 24 voice circuits (DS0's) are combined to form one DS1
- 28 DS1's can be combined (multiplexed) to form a DS3.
- DS3 transmission system carries 24 voice circuits X 28 DS1's, which equals 672 channels

- Circuit switched means when you're out of circuits – you're out of circuits

Microwave Transport

- Licensed Bands 960 MHZ, and 4.9, 6, 11, 18, 23 GHz
- Unlicensed Bands 925 MHz, 2.4, 5.6 GHz
- "last-mile" Gigabit Ethernet popular on 60 & 80 GHz
- All licensed links are regionally coordinated



FCC Part 97 Amateur Microwave Bands

1240 -1300 MHz

2.30 – 2.31 GHz

2.39 – 2.45 GHz

3.30 – 3.50 GHz

5.650 – 5.925 GHz

10.0 – 10.5 GHz

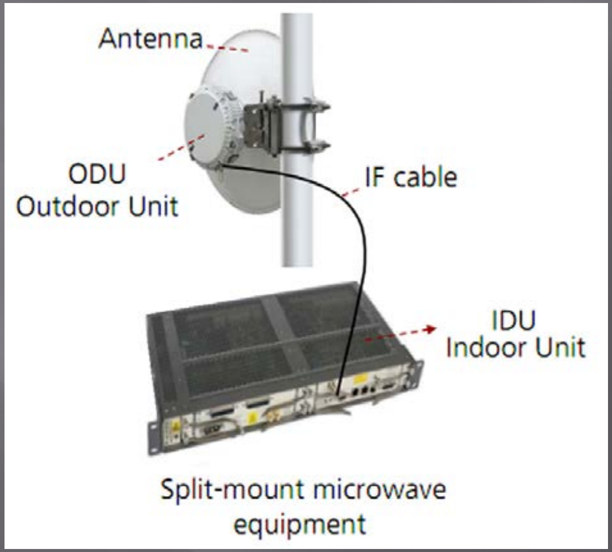
24.0 – 24.25 GHz

47.0 – 47.2 GHz

Microwave Transport

Hardware Configurations

- Indoor Mount
- Split Mount
- Outdoor Unit (ODU)

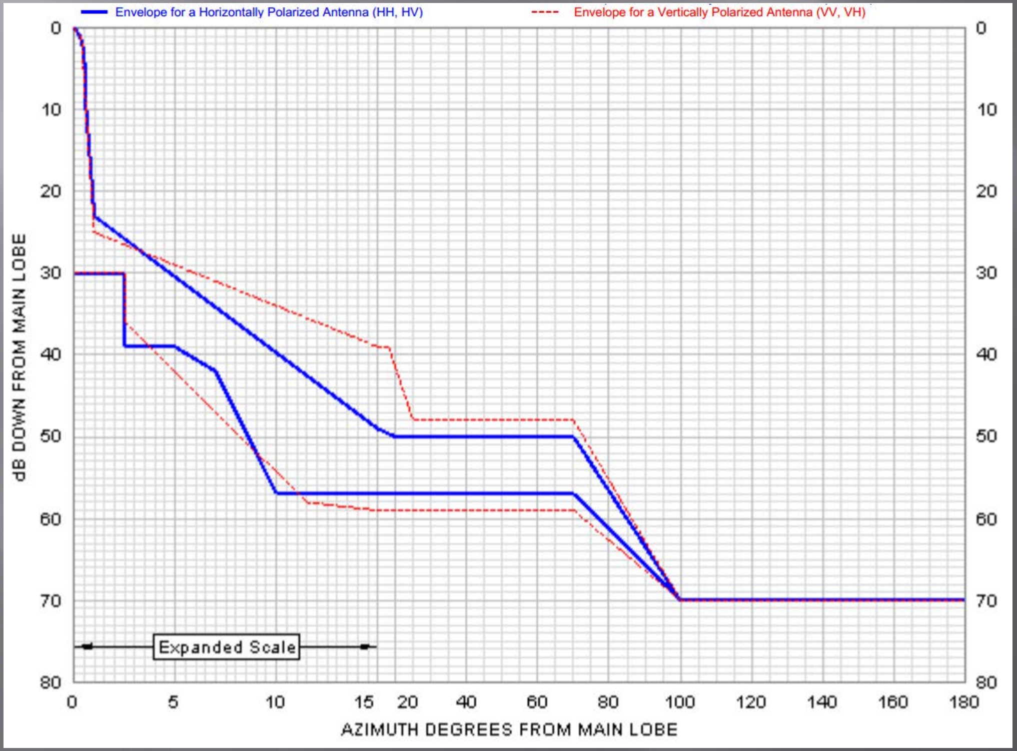


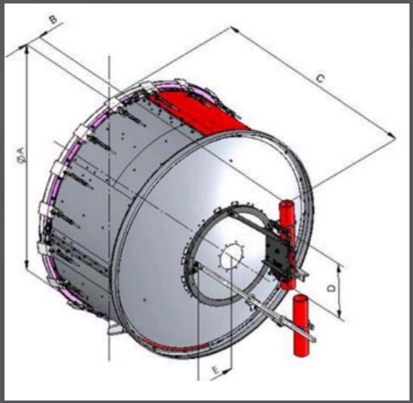
Split-mount microwave equipment

Microwave Transport

High Performance Dish Antennas

- 6′ & 10′diameter (typical)
- 350 lbs
- 44 dBi gain
- Wind loading 700 ft-lbs side, 1300 ft lbs axial





Microwave Transport

Transceiver Specifications (typical @ 11 GHz)

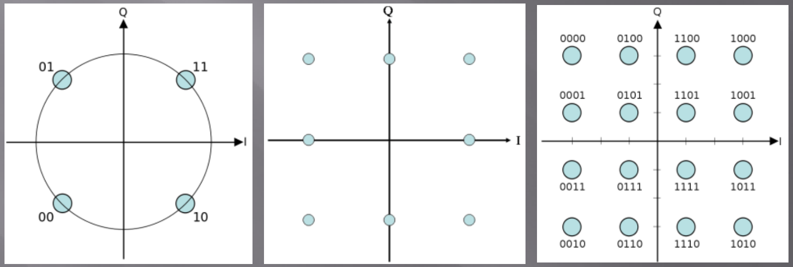
- Output power +15 dBm (32 mW) without PA
- Output Power +23 dBm ~ 30 dBm (200 mW – 1 watt) with PA
- Channel Bandwidths 1.25, 2.5, 5, 10, 30 MHz

BW	1.25 MHz	2.5 MHz	5 MHz	10 MHz	30 MHz
T1	4 x DS1	8 x DS1	16 x DS1	32 x DS1	32xDS1
IP*	8 Mb/s	12 Mb/s	24 Mb/s	50 Mb/s	150 Mb/s
* Ethernet forwarding capacity, not channel data rate					

Microwave Transport

Digital Modulation Schemes

- Can support multiple modulation formats:
- Multi-level Quadrature Amplitude Modulation (QAM) for higher data rates, Quadrature Shift Phase Keying (QPSK) for lower data rates
- Higher order modulation = faster data (bits per symbol), but more susceptible to noise and BER.

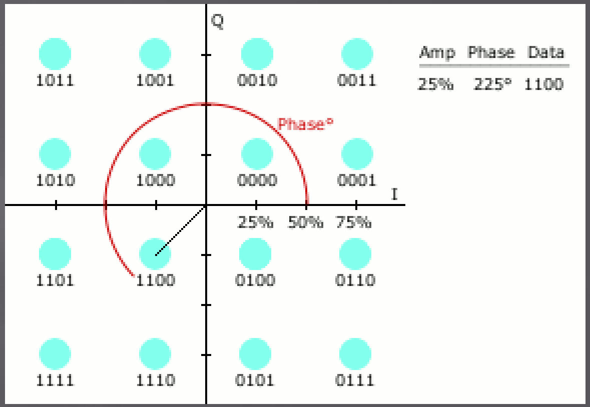


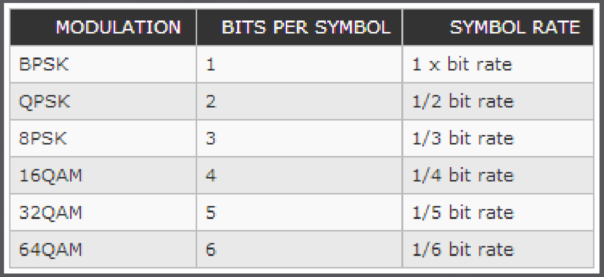
QPSK

8-QAM

16-QAM

Digital Modulation Constellation Diagrams



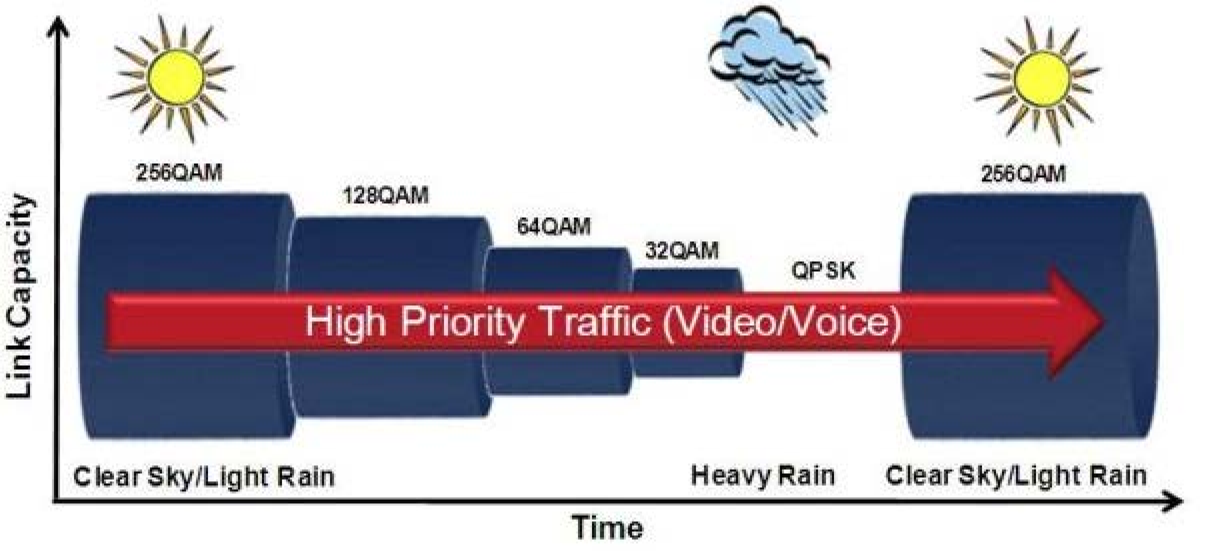


MODULATION	BITS PER SYMBOL	SYMBOL RATE
BPSK	1	1 x bit rate
QPSK	2	1/2 bit rate
8PSK	3	1/3 bit rate
16QAM	4	1/4 bit rate
32QAM	5	1/5 bit rate
64QAM	6	1/6 bit rate

Microwave Transport

Adaptive Modulation

- Improves MW link efficiency by increasing network capacity - while reducing sensitivity to environmental interferences
- Dynamically varies modulation (QAM, BPSK, QPSK) in to maximize throughput under momentary propagation conditions



Microwave Transport

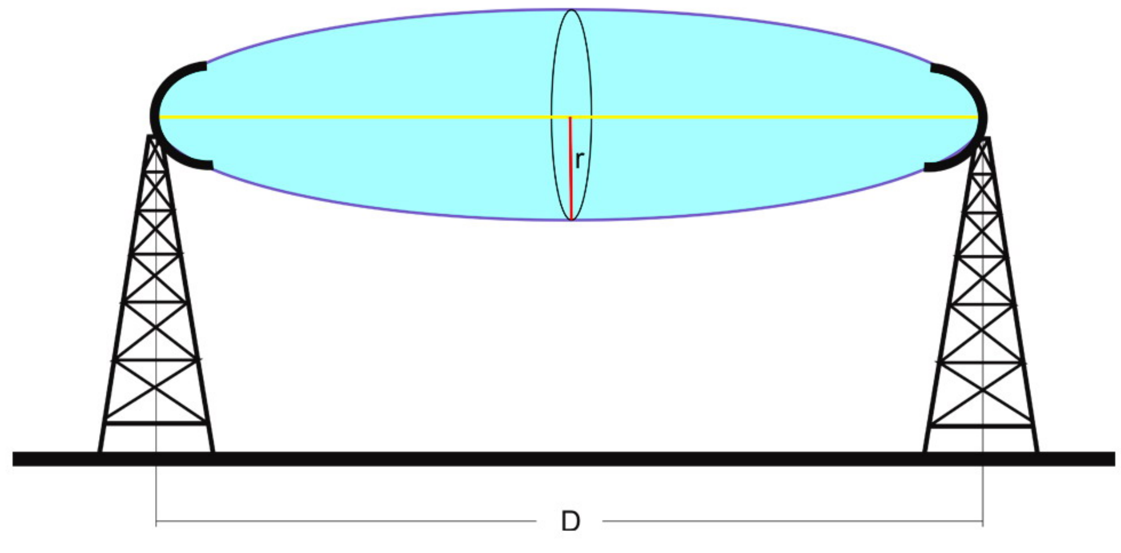
Microwave Engineering

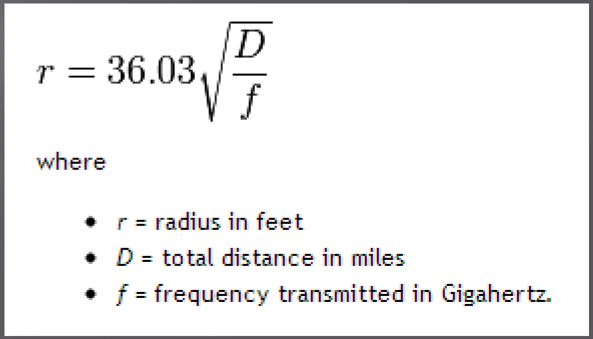
- Path Analysis is very critical
- Software and optical needed for 100 % reliability
- Must consider electrical, mechanical, topography and regional weather environment

Microwave Transport

Fresnel Zones

- Concentric ellipsoids defining radiation pattern of a circular aperture.
- Result from diffraction by the circular aperture.





$$r = 36.03\sqrt{\frac{D}{f}}$$

where

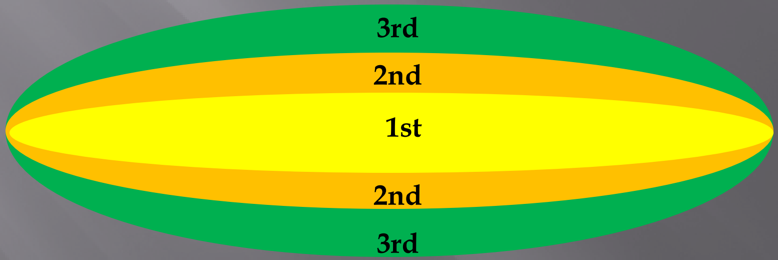
- r = radius in feet
- D = total distance in miles
- f = frequency transmitted in Gigahertz.

Microwave Transport

Fresnel Zones

- For best RSL Fresnel zone must be obstruction free
- Line of sight design not good enough
- Why? Absorption and Phase cancellation

Fresnel Zone	Phase	Comments
1	0° - 90°	Max 20% - 40%
2	90° - 270°	Obstructions here bad
3	270° - 450°	Destructive or constructive

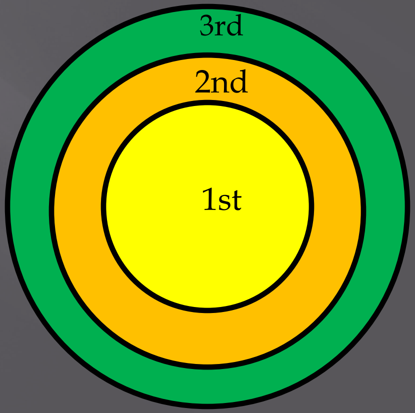


Fresnel Zones

First

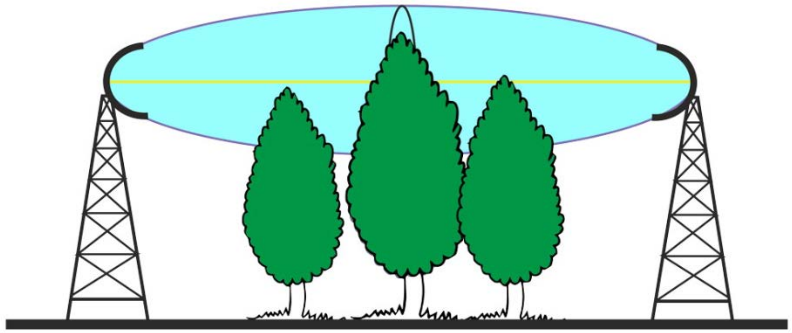
Second

Third



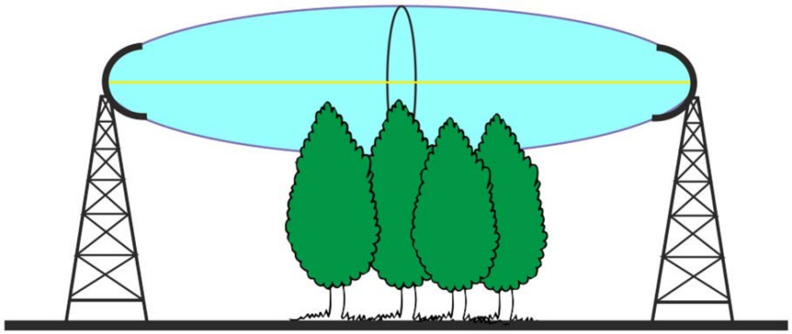
Microwave Transport

BAD



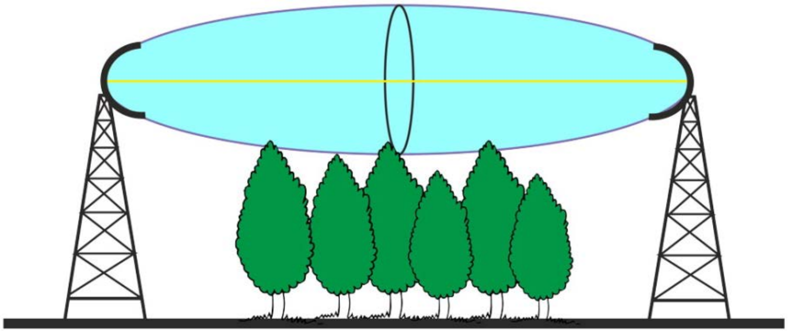
LOS? - No
1st FZ obstructed? - Yes

POOR



LOS? - Yes
1st FZ obstructed? - Yes

GOOD



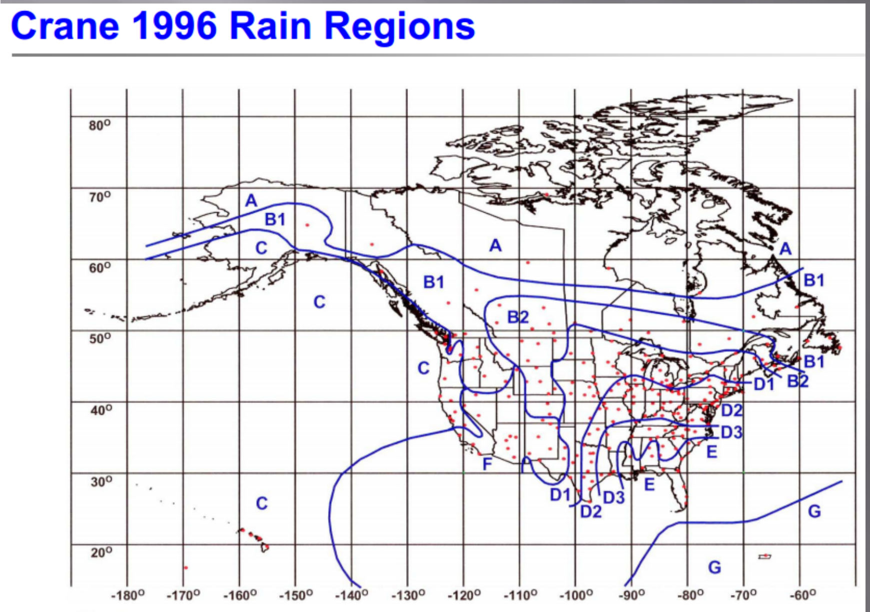
LOS? - Yes
1st FZ obstructed? - No

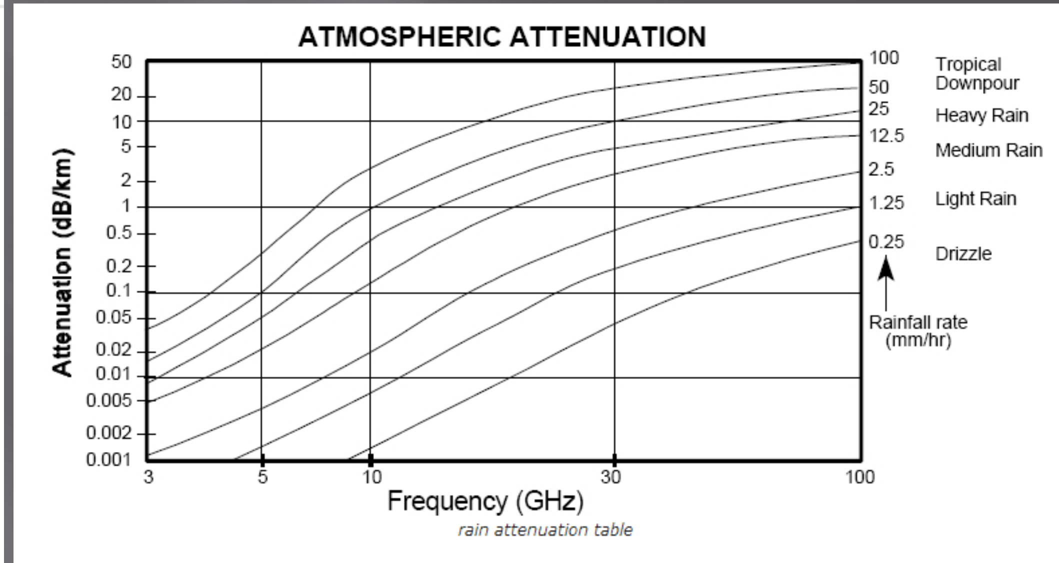
Microwave Transport

Microwave Transport

Other Issues

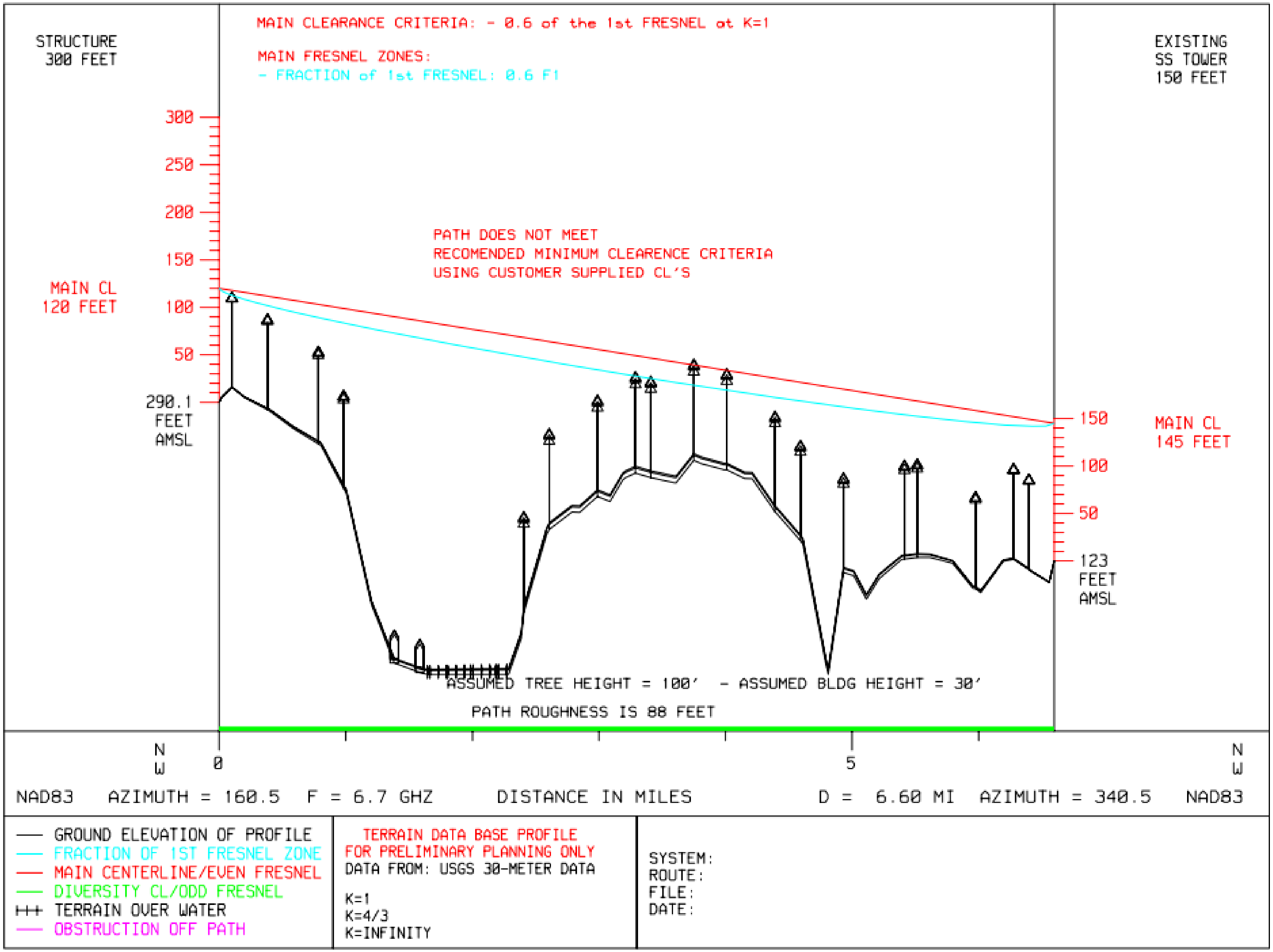
- Over-water Paths – multi-path reflections
- Rain Fade – absorption esp. at higher frequency
- Tree growth & Urban growth – now vs. future
- BW vs. performance tradeoff


Crane 1996 Rain Regions


ATMOSPHERIC ATTENUATION

rain attenuation table

Microwave Path Profile



MAIN CLEARANCE CRITERIA: - 0.6 of the 1st FRESNEL at K=1

MAIN FRESNEL ZONES:
- FRACTION of 1st FRESNEL: 0.6 F1

PATH DOES NOT MEET
RECOMENDED MINIMUM CLEARENCE CRITERIA
USING CUSTOMER SUPPLIED CL'S

ASSUMED TREE HEIGHT = 100' - ASSUMED BLDG HEIGHT = 30'

PATH ROUGHNESS IS 88 FEET

NAD83 AZIMUTH = 160.5 F = 6.7 GHZ DISTANCE IN MILES D = 6.60 MI AZIMUTH = 340.5 NAD83

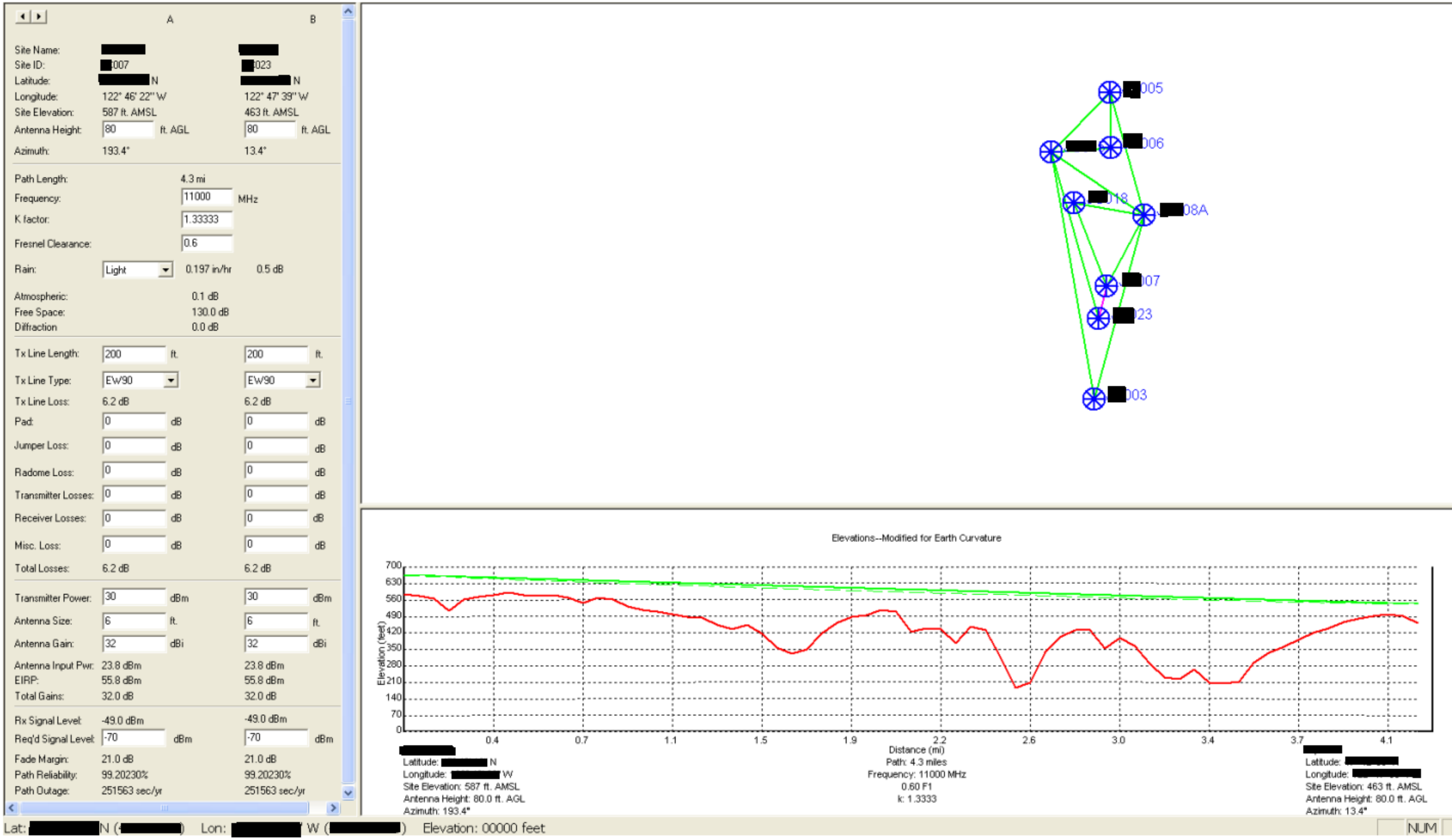
— GROUND ELEVATION OF PROFILE
— FRACTION OF 1ST FRESNEL ZONE
— MAIN CENTERLINE/EVEN FRESNEL
— DIVERSITY CL/ODD FRESNEL
┼┼┼ TERRAIN OVER WATER
— OBSTRUCTION OFF PATH

TERRAIN DATA BASE PROFILE
FOR PRELIMINARY PLANNING ONLY
DATA FROM: USGS 30-METER DATA

K=1
K=4/3
K=INFINITY

SYSTEM:
ROUTE:
FILE:
DATE:

Microwave Path Profile



	A		B
Site Name:	[redacted]		[redacted]
Site ID:	[redacted]007		[redacted]023
Latitude:	[redacted] N		[redacted] N
Longitude:	122° 46' 22" W		122° 47' 39" W
Site Elevation:	587 ft. AMSL		463 ft. AMSL
Antenna Height:	80 ft. AGL		80 ft. AGL
Azimuth:	193.4°		13.4°
Path Length:		4.3 mi	
Frequency:		11000 MHz	
K factor:		1.33333	
Fresnel Clearance:		0.6	
Rain:	Light	0.197 in/hr	0.5 dB
Atmospheric:		0.1 dB	
Free Space:		130.0 dB	
Diffraction		0.0 dB	
Tx Line Length:	200 ft.		200 ft.
Tx Line Type:	EW90		EW90
Tx Line Loss:	6.2 dB		6.2 dB
Pad:	0 dB		0 dB
Jumper Loss:	0 dB		0 dB
Radome Loss:	0 dB		0 dB
Transmitter Losses:	0 dB		0 dB
Receiver Losses:	0 dB		0 dB
Misc. Loss:	0 dB		0 dB
Total Losses:	6.2 dB		6.2 dB
Transmitter Power:	30 dBm		30 dBm
Antenna Size:	6 ft.		6 ft.
Antenna Gain:	32 dBi		32 dBi
Antenna Input Pwr:	23.8 dBm		23.8 dBm
EIRP:	55.8 dBm		55.8 dBm
Total Gains:	32.0 dB		32.0 dB
Rx Signal Level:	-49.0 dBm		-49.0 dBm
Req'd Signal Level:	-70 dBm		-70 dBm
Fade Margin:	21.0 dB		21.0 dB
Path Reliability:	99.20230%		99.20230%
Path Outage:	251563 sec/yr		251563 sec/yr

Elevations--Modified for Earth Curvature

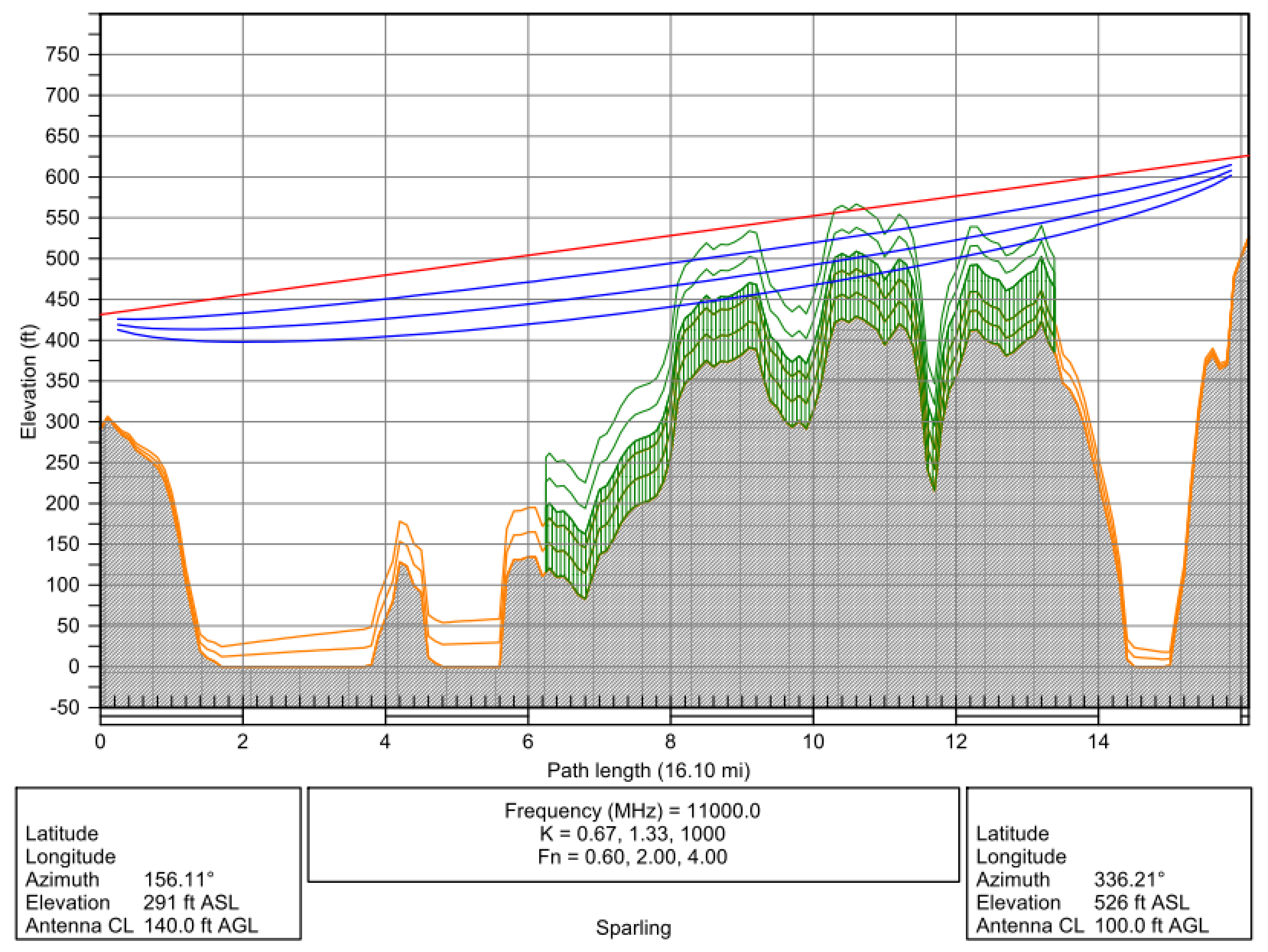
[redacted]
Latitude: [redacted] N
Longitude: [redacted] W
Site Elevation: 587 ft. AMSL
Antenna Height: 80.0 ft. AGL
Azimuth: 193.4°

Path: 4.3 miles
Frequency: 11000 MHz
0.60 F1
k: 1.3333

[redacted]
Latitude: [redacted]
Longitude: [redacted]
Site Elevation: 463 ft. AMSL
Antenna Height: 80.0 ft. AGL
Azimuth: 13.4°

Lat: [redacted] N ([redacted]) Lon: [redacted] W ([redacted]) Elevation: 00000 feet

Microwave Path Profile



Latitude	
Longitude	
Azimuth	156.11°
Elevation	291 ft ASL
Antenna CL	140.0 ft AGL

Frequency (MHz) = 11000.0
K = 0.67, 1.33, 1000
Fn = 0.60, 2.00, 4.00

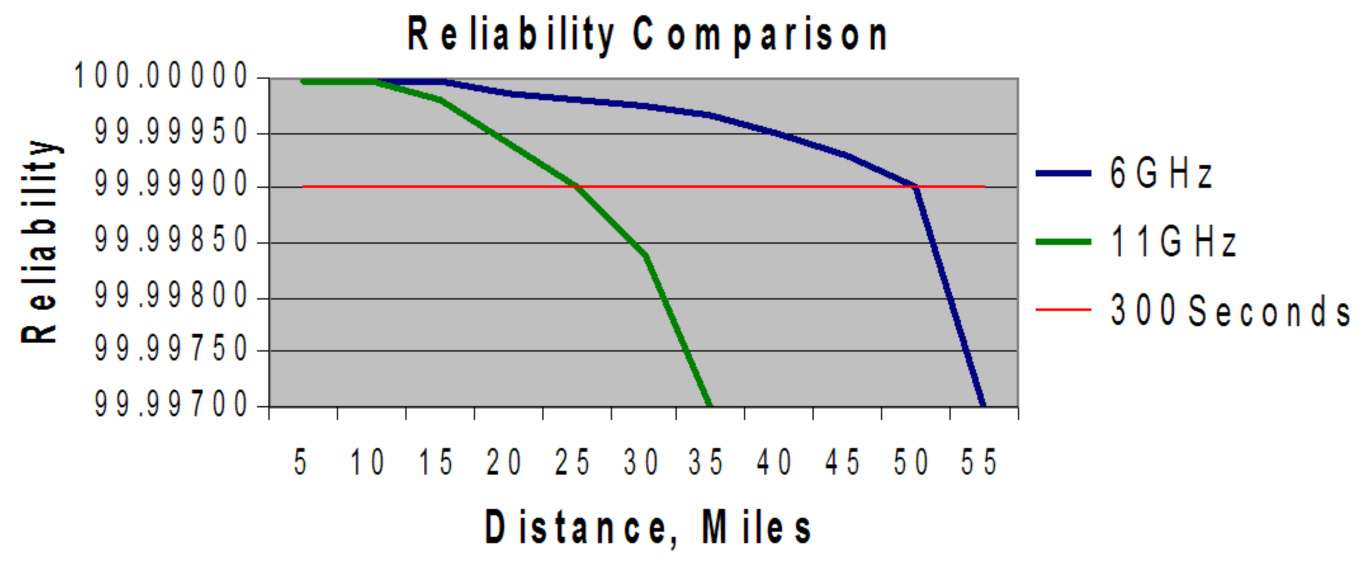
Sparling

Latitude	
Longitude	
Azimuth	336.21°
Elevation	526 ft ASL
Antenna CL	100.0 ft AGL

Microwave Transport

Design Goal

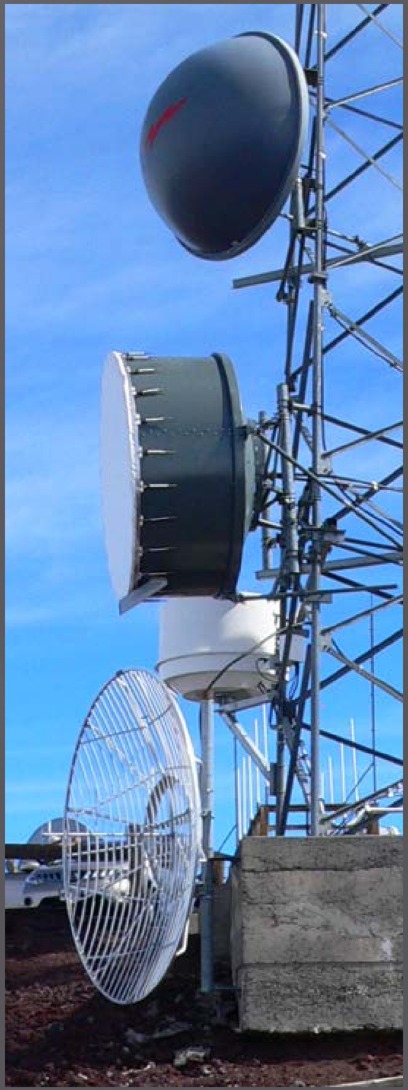
- "Five nines" of reliability (= < 5 mins/year outage)
- Achieved by multiple methods
- Signal Fading is the enemy



Microwave Transport

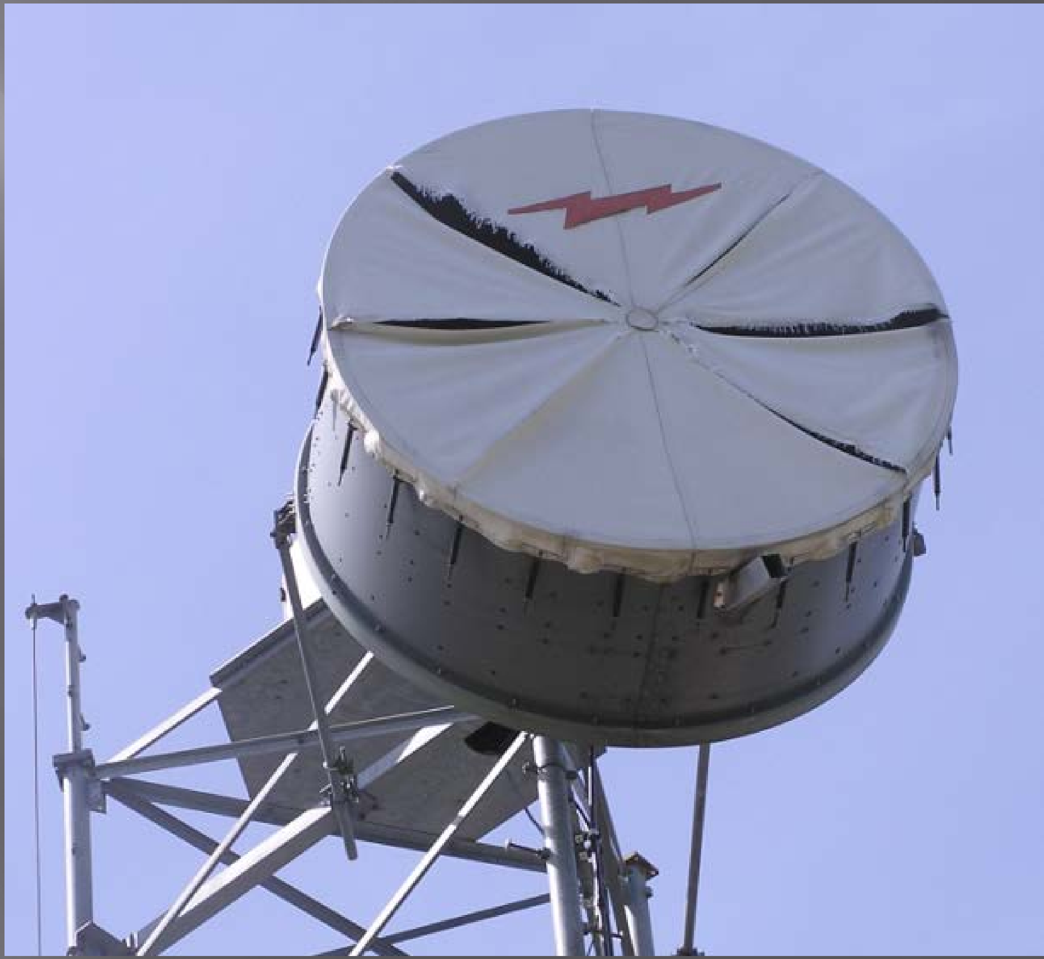
Parabolic Antenna Types

- Grid
- Standard
- Shielded



Microwave Transport

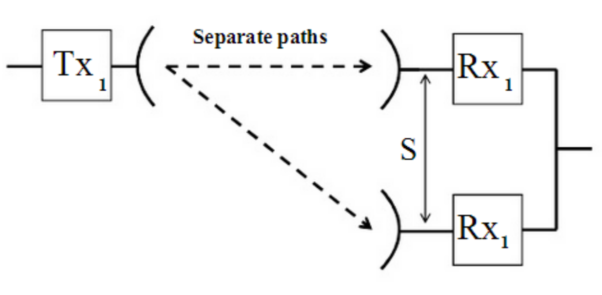
Ice Shields provide critical protection from the elements



Microwave Transport

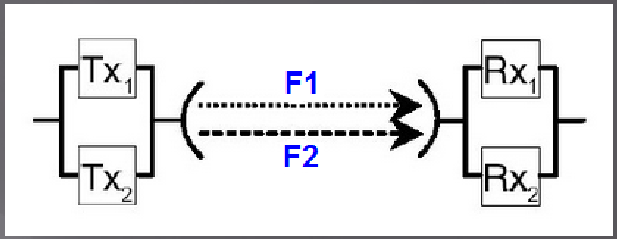
Space Diversity

- Dual Rx antennas
- Top primary, lower secondary



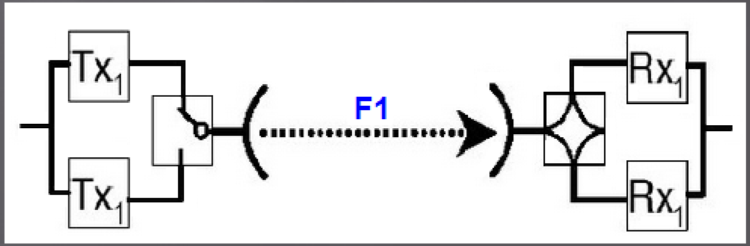
Frequency Diversity

- Signal transmitted over separate frequencies



Hot Standby

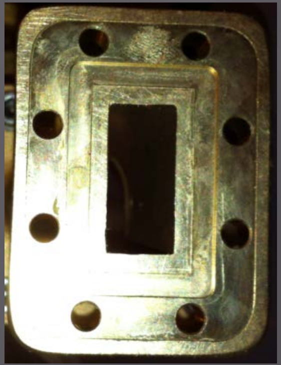
- Spare Tx key-down into load
- Spare Rx in standby



Microwave Transport

Waveguide Transmission Line

- Used above (typically 3 GHz)
- Shielded, low loss, good for high power
- Elliptical and Rectangular designs
- Constant Impedance over wide frequency range
- No center conductor
- Transverse Electromagnetic Mode (TEM) propagation - E & H field lines are restricted to directions normal (transverse) to propagation direction



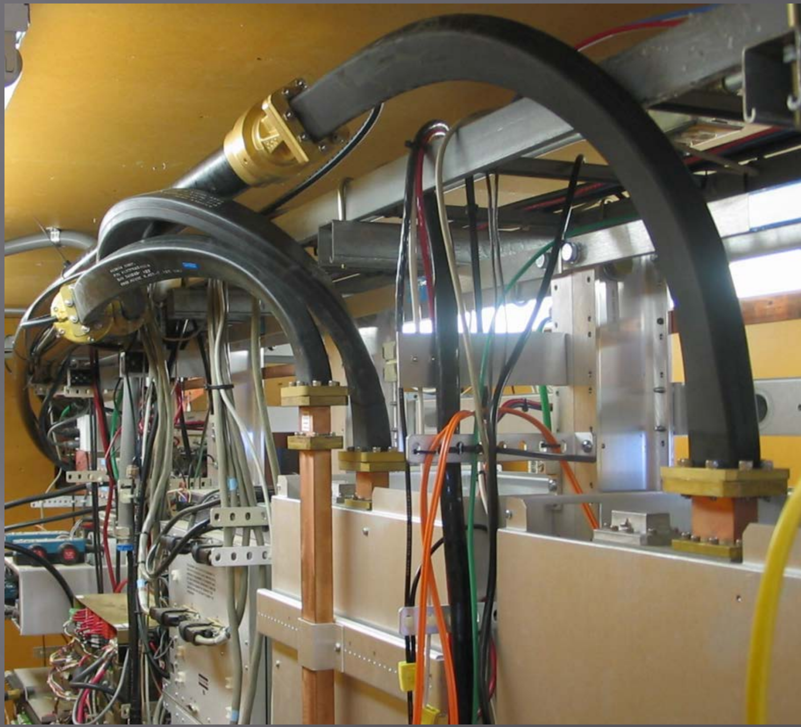
Microwave Transport

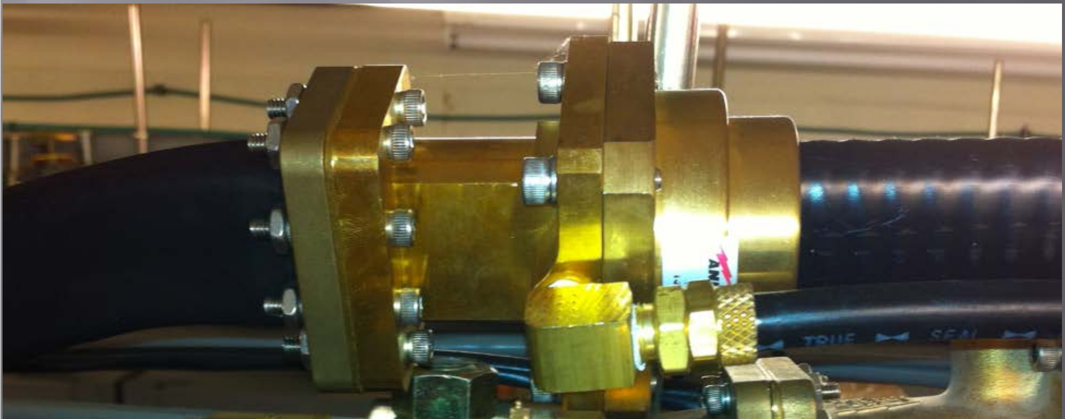
Many Waveguide Components

- Straight sections, 90° E- and H- Bends
- 90° Twist section, Pressure windows
- Waveguide to type N Adapter

All the classic components

- Duplexer, splitters, diplexers, etc.

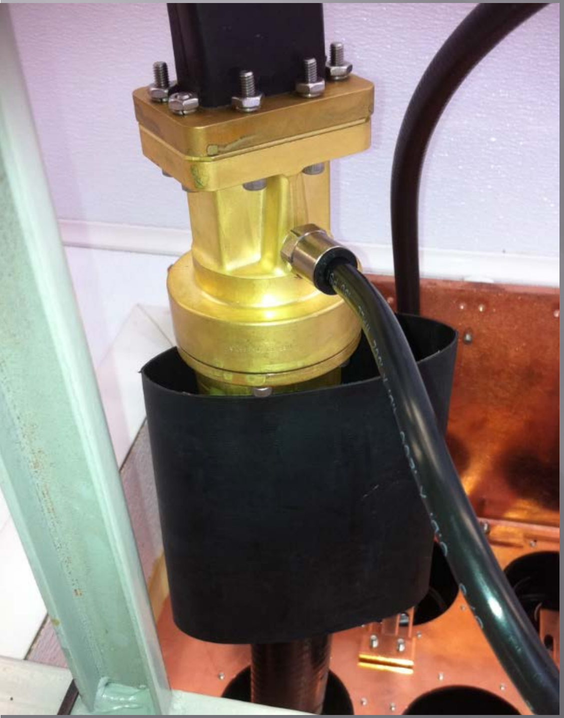


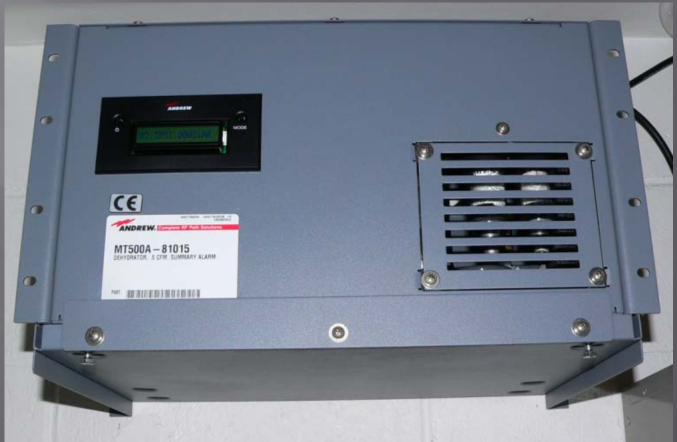


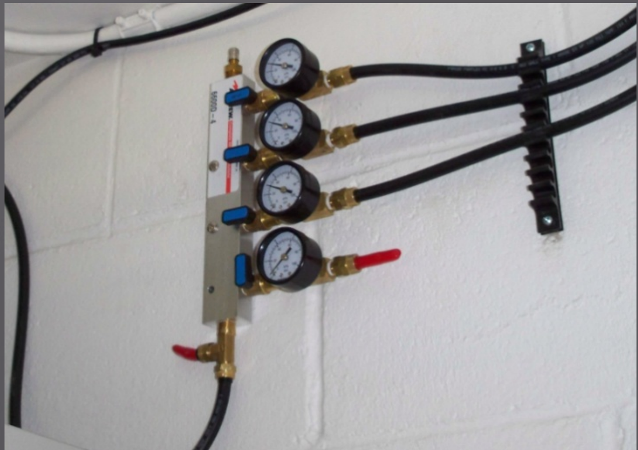
Microwave Transport

Waveguide internal environment must be managed

- Must be kept clean and dry
- Compressor and dehydrator system (typ. +5 psi above atmosphere)
- Many mechanical connections and transition flanges







The END

QUESTIONS ?